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The Story of the Maize Plant

Paul Weatherwax

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THE UNIVERSITY OF CHICAGO PRESS
CHICAGO, ILLINOIS

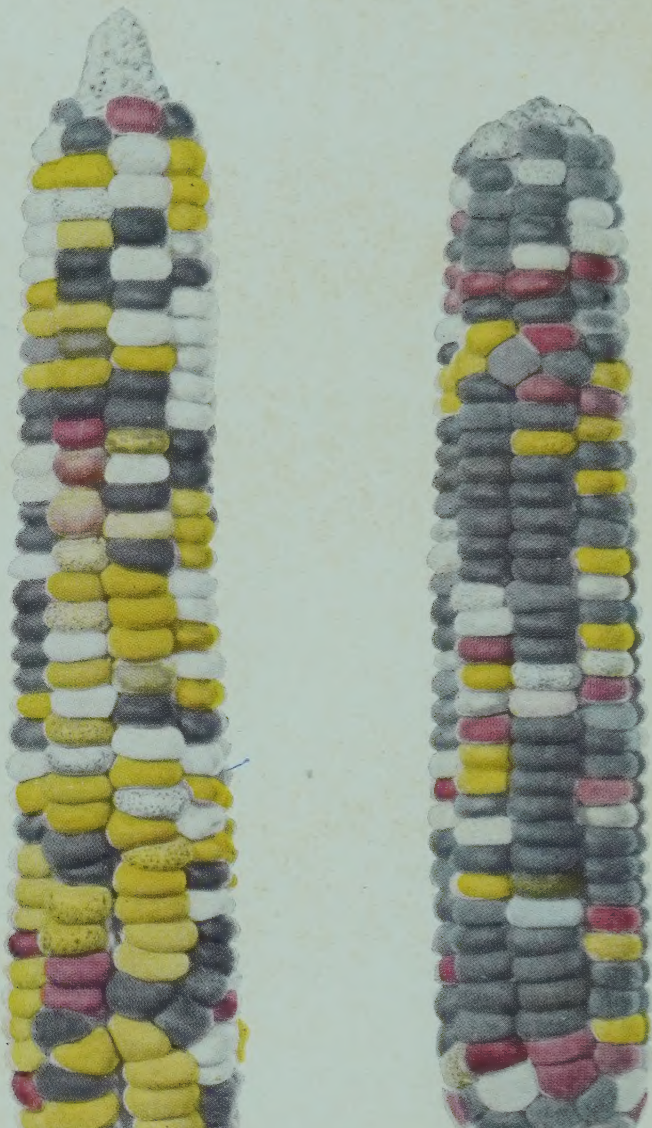
THE BAKER AND TAYLOR COMPANY
NEW YORK

THE CAMBRIDGE UNIVERSITY PRESS
LONDON

THE MARUZEN-KABUSHIKI-KAISHA
TOKYO, OSAKA, KYOTO, FUKUOKA, SENDAI

THE MISSION BOOK COMPANY
SHANGHAI

PLATE I



COLORS OF THE ENDOSPERM OF MAIZE

For explanation of plate see p. 162

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THE UNIVERSITY OF CHICAGO PRESS
CHICAGO, ILLINOIS

Published March 1923

Composed and Printed By
The University of Chicago Press
Chicago, Illinois, U.S.A.

PREFACE

Numerous inquiries for specific information about the maize plant have come to the writer in the course of the past five or six years, during which a series of investigations on its botanical nature have been in progress; and it is in an attempt to meet, in a measure, an apparent need that the following pages have been prepared.

The reliable literature on maize is voluminous, but it is so widely scattered in textbooks and periodicals, and so intermingled with the unreliable, that it is often a hopeless task for the technical worker in other fields, or for the casual reader, to bring a particular unit of the material together and to separate the grain from the chaff for any definite purpose.

A dozen or more monographs of the species have appeared in different countries in the past century, but they do not answer satisfactorily today the questions that the reading public is asking. Some have not yet been released from the foreign languages in which they were written, and are often couched in terms of the prejudiced or distorted point of view of the investigator where maize is known only as an exotic curiosity; others are out of step with modern scientific tendencies; and still others, the majority of the list, in fact, are so dominated by economic interest that their theme is *man* rather than *maize*.

No claim is made for completeness or perfectly rounded proportion in this treatment. These are but relative terms anyhow, and judgment must be individual.

If this work is as poorly proportioned in some respects as its predecessors have been in others, the writer can but hope that its idiosyncrasies will make it interesting to a class of readers by giving emphasis to aspects less adequately treated elsewhere.

With few exceptions, the illustrations have been prepared by the writer, and many of them especially for this work. In so far as has been possible, the drawings have been made directly from the material or from photographs. A consistent effort has been made to correct in these figures some of the gross errors that prevail in textbooks where maize is used for illustration.

Free use has been made of material previously published by the writer in short papers. Any difference in opinion or in statement of fact noted here may be interpreted as corrections of errors that have been discovered in the earlier articles subsequent to their publication.

As indicated in the notes and references, many sources of information have been drawn upon in an attempt to get at the truth. This has been greatly facilitated by the kindness of many other investigators, in this and in other countries, who have sent material, notes, and literature. In several instances, advantage has been taken of unpublished criticism by other workers; and throughout the preparation of this work and the researches that preceded it, Professor D. M. Mottier has given encouragement, criticism, and suggestions of inestimable value. Responsibility for the final form, however, and for views taken on points in controversy, rests wholly with the author.

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CHAPTER I

INTRODUCTION

It was deep in the mists of the past, long before the advent of the human race, that Nature inaugurated among her gramineous plants and their environment the set of principles eventually to give rise to the cereals, those large-seeded grasses which provide today the chief source of food for man and his domestic animals. After one plan or another she devised for oriental lands their rice and their millets, for Africa and parts of Asia the sorghum family, and for the Semite in his desert garden and the Aryan on his westward migrations, the small grains of Europe and Asia. For the vast wilderness of the Western Hemisphere, however, she had only a single corn plant; but she put into its creation the best of all that had been given to the cereals of the Old World; and, somewhere in the hills or plateaus of the American tropics, there came into existence that economically indispensable and botanically unique species that we call *maize* or *Indian corn.*

For untold seasons, the plant grew and extended its domain, the savage primate doubtless coming, meanwhile, with the other animals, to eat its stems and fruits. As man returned year after year, and animal competition made the limited habitat of the plant an uncomfortable place, he began to carry away choice morsels to eat in a more quiet spot. But he was still far from the practice of maize cultivation. Year after year he saw young shoots appear above the ground, grow to flower and fruit,

and die; and, in his primitive way, he must have wondered at it all. It may have been a fallen ear bearing a tuft of seedlings, or a germinating seed at the entrance of his den, that first told the savage that one of the gods back of the phenomenon was the fruit that he was accustomed to pick from the mature plant; and, later, he probably noticed that young plants appeared regularly in new places where seeds had been dropped accidentally. As soon as he learned to bury a few seeds where he wished new plants to be, progress became more rapid; and knowledge as to the season and methods of preparing the soil, planting, and cultivation made its own slow way in due time. Much later he learned to use as seed the best of the grain produced, and with this the agricultural evolution of the species had begun.

When the closing events of the fifteenth century opened the wonders of a new world to the old, the explorer looked with hardly more wonder upon the native American himself than upon his extensive fields of this uniquely useful plant. The maize plant was the economic stepping-stone of the colonist in temperate North America, and the banner of the immigrant as he made his way into the Mississippi Valley; and today the Corn Belt is the land of rationalism, prosperity, and happiness—the social and economic bulwark of the nation. In other countries where it has been introduced, this corn plant has immediately become popular in one way or another, but it grows best and is still most appreciated in its native land.

A large part of our knowledge of the maize plant has been derived from studies directed from the prejudiced point of view of the utilitarian. These studies

have concerned themselves with methods of manipulation, environmental relations, rating and improvement of varieties, feeding values, and distribution and utilization. The aim of work of this kind has been to make the plant serve in a better way the needs of man; and the organization of facts and theories bearing in this direction is now far in advance of their application.

But the biological individuality of the plant has been the guiding inspiration of other studies. Here we attempt to eliminate the influence of man's point of view and get at that of the plant. We are interested in the plant as a plant, with a beautifully characteristic structure, problems of its own to solve, a life of its own to live, and a part of its own to play in the drama or organic existence.

CHAPTER II

NAMES AND RELATIONSHIPS

When the explorer makes his way into an unknown land, each prominent species of plant or animal is subject to at least three processes of nomenclature before it is fully catalogued as an acquisition of civilization. One popular name will be based upon the native appellation, if one exists; another will consist of a modification of the term applied to the new organism's nearest relative in the language of the explorer; and to these must be added in time the binomial designation of science. The great American cereal has met with these three tendencies, and each has given it a permanent name.

Common names.—On discovering this plant in the West Indies, Columbus adopted as its name the word *mayz*, a derivative of the native name in many dialects; and from this has come our modern word *maize*. But the Anglo-Saxon's first extended acquaintance with the plant was made not so much through exploration in America as in the fields and gardens of Europe, where it had been introduced; and, in the absence of the direct influence of the native name, its derivatives were accorded less favor than they deserved. The name *maize* remains today the simplest, most expressive, and most definite common name of the species; and it is unfortunate that it has not attained a more general use, especially in the United States.

For centuries the English-speaking peoples have applied to all the cereals the class name *corn*, the term

often being used specifically for the commonest grain crop in any definite locality. On the introduction of maize, the use of the existing term was extended, and the new cereal came to be known as *Indian corn* in many countries of Europe; but to a hundred million Americans today, maize is merely *corn*.

Many other common names have been used in limited localities at different times. These usually treat the plant as a kind of corn or wheat, the qualifying prefix often indicating the route of introduction into that particular locality. Thus we find such names as Turkish corn, Turkish wheat, Indian wheat, Roman corn, Sicilian corn, and Indian millet. In South Africa, where the plant has recently assumed great economic importance, it is known as *mealies*, probably a corruption of a word for millet.

Technical names.—When maize came under the hand of the great Swedish systematist, early in the eighteenth century, it received the botanical name by which it is still known, *Zea Mays*.[1] In consideration of the nature of the plant and the part that it has played in history, the name is well chosen. *Zea* is from the Greek name of a cereal, and this is, in turn, derived from a verb meaning "to live." This is in accord with Indian nomenclature, many versions of their word for maize meaning "that which sustains us." The specific name is derived from the aboriginal.

An endless number of synonyms have come into more or less common use as a result of the discovery of new varieties supposed to be worthy of specific rank, attempts

[1] Usage with regard to the spelling and capitalization of the specific name is not uniform, the following occurring in current literature: *Mays*, *mays*, *Mais*, *mais*, *Maïs*, and *maïs*. The first-named form seems to be preferred.

to give technical names to agricultural varieties, the recognition of the use of the word *Mays* in a generic sense, or a misunderstanding of the nature and relationships of the species. The following list of synonyms is given merely for purpose of illustration and is in no way intended to be complete:

Zea alba Mill.	*Zea indentata* Sturt.
Zea altissima Gmel.	*Zea everta* Sturt.
Zea hirta Bonaf.	*Zea indurata* Sturt.
Zea rostrata Bonaf.	*Zea saccharata* Sturt.
Zea praecox Pers.	*Zea tunicata* Sturt.
Zea Curagua Molm.	*Zea Mays tunicata* St. Hil.
Zea canina Wats.	*Zea Mays rugosa* Bonaf.
Zea minor Gmel.	*Mays zea* DC.
Zea macrosperma Klotsch.	*Mays americana* Baum.
Zea cryptosperma Bonaf.	*Mays vulgaris* Seringe
Zea ramosa Gernert	*Triticum indicum* J. Bauh.
Zea amylacea Sturt.	*Frumentum turcicum* Blackw.

The aim of this multiplication of nomenclature, especially the naming of varieties, has been to simplify and elucidate the situation; but the end has been only ridiculous confusion. The varieties and subspecies named are usually based upon only one or a small group of characteristics and have no biological identity. It is possible for a single individual to belong, without question, to two or more groups named co-ordinately, even by the same authority—a situation hardly in accord with the spirit and functions of the binomial system. For example, a single plant of podded dent corn would be simultaneously *Zea tunicata* Sturt. and *Zea indentata* Sturt. If it had pistillate flowers in its tassel, it would be proper in the nomenclature of others to call it *Zea androgyna*.

An almost endless number of agricultural varieties are already in existence, and new ones can be synthesized

almost at will by hybridization; and, if any be named, all should be. Our problem is not so much to find names enough for all as it is to stop the making of new names soon enough to enable a name to mean anything. The logical thing to do is to recognize in *Zea* a variable, complex genus, whose primary subdivisions have been irrevocably lost by fusion through hybridization. The only name not overlapping others is the generalized *Zea Mays* L., or its synonyms based upon other generic names; references to variations and to agricultural varieties may better be made by structural and physiological terminology than by Linnaean binomials. The success with which this method is followed in general botany is its justification.

Classification.—Maize belongs to that great family of monocotyledonous plants technically designated as *Gramineae*, and commonly known as *grasses*. The group, as a whole, is too well known to require a detailed definition. Most of its members are herbaceous, and they exhibit a wide range of variation in size, form, and habit. Their stems are round or flattened and marked by definite nodes; the internodes are usually hollow. The leaves are arranged in two rows on the stem. The flowers are aggregated in compact spikelets, and these are arranged in many types of inflorescence. The only plants with which the grasses are likely to be confused are the sedges, and they have three-cornered stems and three-ranked leaves.

The tribe, Tripsaceae,[1] consists of seven monoecious genera. At least the staminate spikelets are in pairs, one of each pair being pediceled and the others sessile; they

[1] The equivalent of the old tribe Maydeae. See Hitchcock's revision of the family (79). (Figures refer to the Bibliography, pp. 227–35.)

are two-flowered and determinate, the upper flower in the spikelet being the more advanced in development. The pistillate spikelets are variable in arrangement and structure, and this affords a basis for distinguishing the genera.

Geographically and botanically there are two distinct groups of the Tripsaceae. While there are many points of similarity between these groups, there are also several significant differences; and the phylogenetic relationship between them may be much more remote than is generally believed.

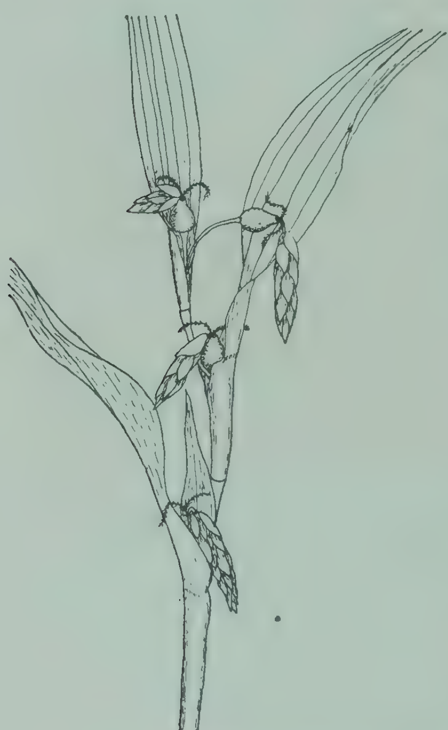


FIG. 1.—Inflorescence of *Coix lachryma-Jobi*.

Four genera—Coix, Sclerachne, Chionachne, and Polytoca—are native of various parts of India, Indo-China, Ceylon, Java, Sumatra, Borneo, Australia, and the Philippines. In all these genera, the fertile floret, and ultimately the fruit, is inclosed in a corneous to stony covering consisting of a single modified glume or foliar sheath. *Coix lachryma-Jobi* L. is the best-known species of the group. Under the common name, "Job's Tears," it is often grown in gardens as an ornamental plant and for its fruits, which are used for beads (Fig. 1). It is now widely distributed over the warmer parts of the world and often persists as an escape from cultivation.

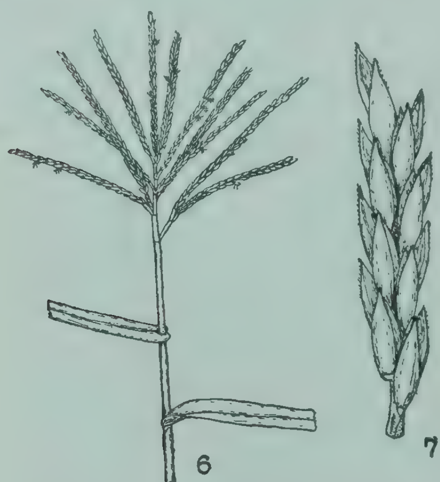
The other group of the Tripsaceae consists of three American genera—Zea, Euchlaena, and Tripsacum. Euchlaena grows wild in Mexco and Central America and has been introduced as a forage plant into other warm countries, where it is known as "teosinté." It seldom matures seeds farther north than the extreme southern parts of the United States. Tripsacum has a much wider range than Euchlaena, occurring at least as far north as the Ohio River, and extending far into South America (Fig. 2).

FIG. 2.—*Tripsacum dactyloides*, cultivated on the campus of Indiana University.

FIGS. 3–5.—Figs. 3, 4, inflorescence and spikelets of Tripsacum. Fig. 5, pistillate inflorescence of Euchlaena.

Maize is readily distinguished from the other American genera by the pistillate inflorescence and the fruit. In Tripsacum both the pistillate and staminate flowers are borne in the same paniculate inflorescence, but in different spikelets (Figs. 3, 4). In

the other two genera the staminate flowers occur in a terminal panicle (Figs. 6, 7) and the pistillate in lateral spikes. The pistillate inflorescence of Euchlaena (Fig. 5) resembles, in some respects, that of Zea, and the generic distinctions are sometimes complicated by the occurrence of mixed inflorescences; but no one who has ever seen an ear of corn has any difficulty in distinguishing maize from its near relatives. Maize is generally regarded as the most highly specialized grass plant in existence.



FIGS. 6, 7.—Staminate panicle and spikelets of Euchlaena.

CHAPTER III

HISTORY AND GEOGRAPHICAL DISTRIBUTION

There is some doubt as to when maize was first seen by civilized man. An old Scandinavian record states that the Northmen, on one or more of their visits to North America nearly a thousand years ago, found "self-sown cornfields," and, on one occasion, a wooden shed for the storage of grain. This brief mention has been taken by many authorities as the first account of maize to be written by a white man. But it seems that a thing so striking as a field of corn would have called for a more extended discussion. The fact that it was passed by merely as "corn"—in sharp contrast with the enthusiasm with which later explorers described it—would lead to the belief that the plant they saw was more like the cereals of Europe; and, if so, it was not maize.

The southern limit reached by the Northmen is still a matter of some doubt. If, as some believe, they did not explore farther south than the mouth of the St. Lawrence, they probably did not come within the range of maize. Moreover, the fact that the cereal was mentioned as "self-sown" points to its being some plant that grew wild, and it is very improbable that wild maize would have been found in northeastern North America if found at all. The plant seen by the Northmen was more probably some wild grass resembling wheat or rye (2, 59, 16).[1]

[1] References given in this way are to the Bibliography, pp. 227–35.

Discovery by Columbus.—The first authentic account of maize is that given by Columbus and his companions on the first voyage of discovery. The record of this voyage tells of finding the plant in cultivation in the West Indies and records its native names, from which the word *maize* has been derived. It is also recorded that, on the occasion of the first-known celebration of Christmas in America, bread made from maize was one of the main constituents of the dinner. Columbus and his men were enthusiastic in their praises of this food, and probably partook of it all the more heartily because they could not screw their courage up to the point of eating with a relish the roasted iguana which constituted the meat course.

The explorations of the sixteenth and seventeenth centuries showed the range of the species to extend from Chile and Argentina on the south to the Great Lakes region on the north (Fig. 8). In all favorable locations in this vast region, it was found in an endless variety of forms and in various states of cultivation, but in no nook or corner of either continent has the wild form ever been found. In historic times the species has been completely dependent upon man for its perpetuation.

Introduction into Europe.—In the meantime, it had been introduced into Europe, first from the West Indies by the Spaniards, and a short time later from Peru. From Spain it was taken into other countries, new introductions being made from America all the while, and, in the sixteenth century, we find it grown as a garden curiosity in Spain, Italy, France, Germany, and England. With the immediate recognition of the plant's usefulness, there began a rapid distribution, which

FIG. 8.—Distribution of maize in aboriginal America. The densely shaded portion in Mexico and Central America is the probable place of origin of maize. In other portions of this and the other maps showing distribution, the density of the shading indicates the relative importance of maize as a crop plant. The data included in this map are from Harshberger (74), Wissler (168), and other sources.

ultimately made it a common agricultural staple in every part of the world that afforded it a favorable

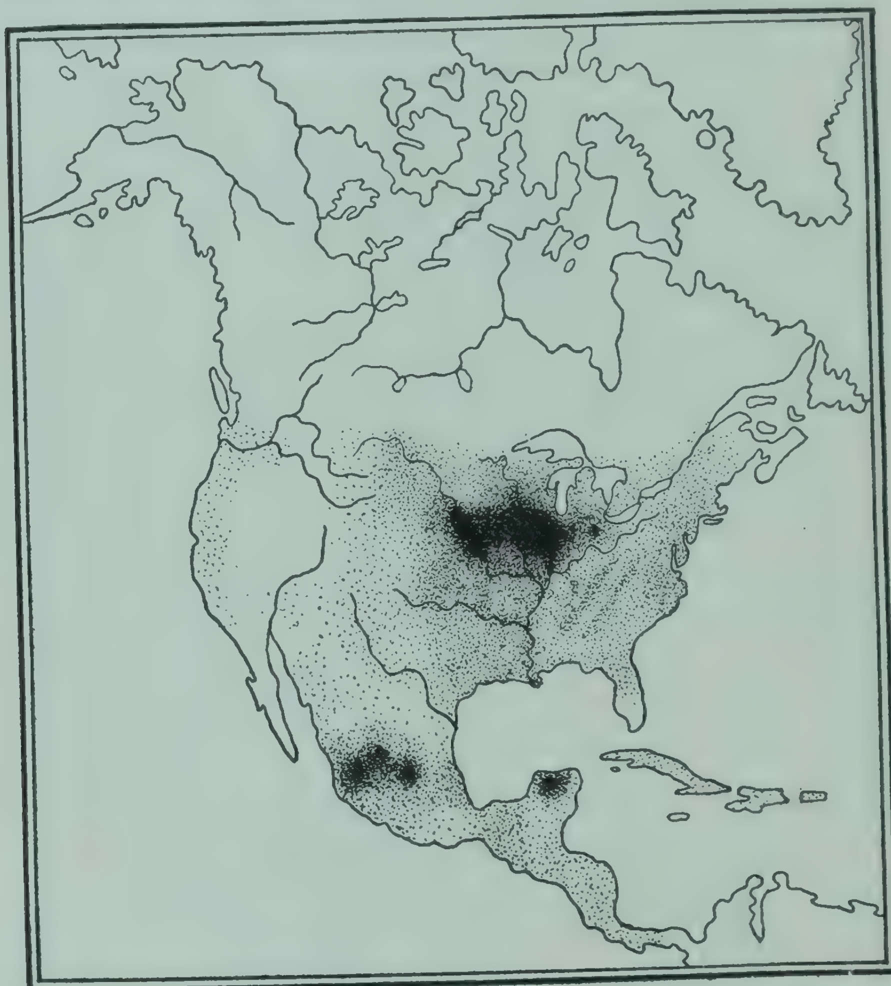


FIG. 9.—Present distribution of maize in North America. The data included in the maps showing the present distribution of maize were secured largely from publications of the United States Department of Agriculture.

climate and soil. The Portuguese distributed it along the coast of Africa, and probably introduced it into China, and it made its appearance in India at about the same time.

Present distribution.—Today maize is extensively grown in Mexico, Argentina, Hungary, Roumania, Italy, Russia, Egypt, India, and South Africa; and, to a less

FIG. 10.—Present distribution of maize in South America

extent, in Canada, Peru, Chile, Central America, Spain, Portugal, France, Germany, China, Japan, Australia, and the Philippines (Figs. 9–13). But it is still principally an American crop, the United States producing

FIG. 11.—Present distribution of maize in Europe

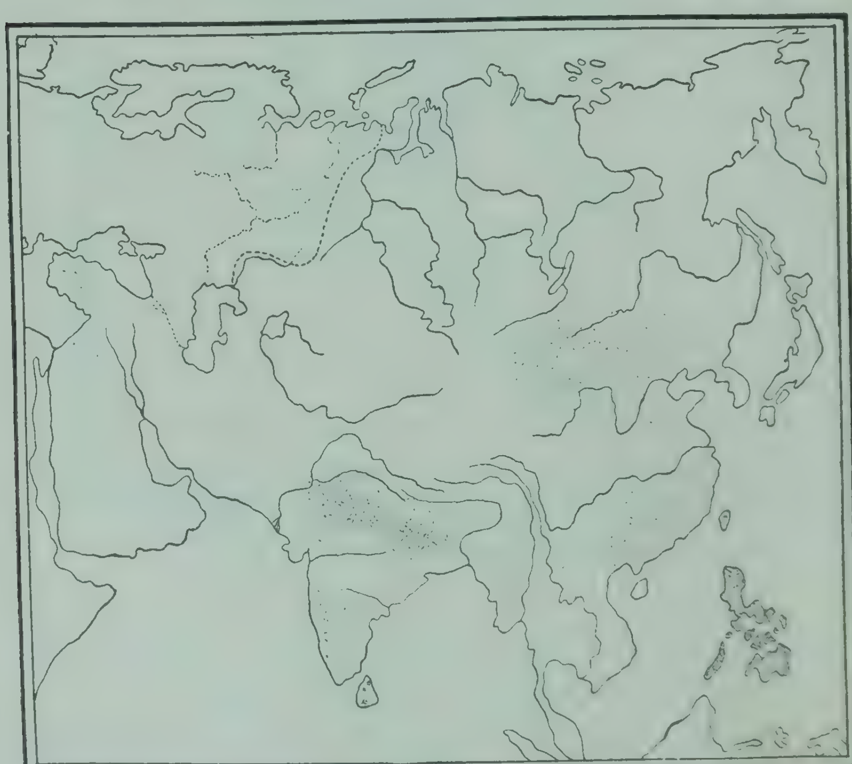


FIG. 12.—Present distribution of maize in Asia

each year three times as much as all other countries together.

Place of origin.—From time to time apparent evidences have been found that maize was a native of other

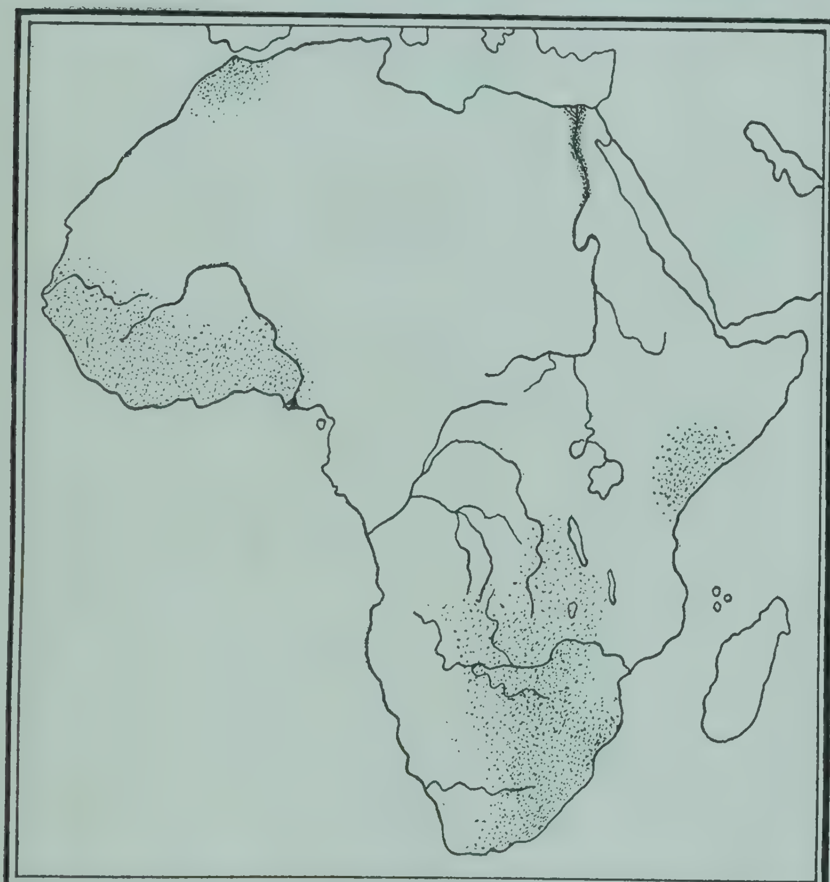


FIG. 13.—Present distribution of maize in Africa

countries than America, but none of these have stood the ultimate test. An ear of corn is said to have been found in a tomb in Egypt, but this occurrence is supposed to have been the work of an impostor. Nothing has been found in Egyptian art or literature, or elsewhere in the ruins, to indicate that the plant was known there

in ancient times. An old account as to how the seed of maize was brought to Europe during the Crusades has been found to be unreliable. If maize had been introduced at this time, or had been known anywhere in the Old World at this time, it would be difficult to explain why it did not gain the rapid dissemination that characterized it later.

FIG. 14.—The first published figure of maize. From an edition of the Pên-tsao-kung-mu, published probably about 1597. The three symbols of the legend constitute the modern Chinese word for maize, *Shu-cho-yü*. Their literal meaning is: *shu*, millet, or cereal; *Cho*, Szechwan, a province of Western China; and *yü*, a gem, or precious stone. To the Chinese of that day, then, maize was known as a cereal which resembled a precious stone and came from Szechwan. For the literal translation of these terms, I am indebted to one of my former students, Mr. C. C. Feng. Figure from Bonafous' copy of original.

Several accounts in Chinese literature of the sixteenth century have been cited as evidence that maize was known in China in pre-Columbian times. The one figure given in a book published between 1552 and 1578, or possibly as late as 1637, might as well be taken for some other grass than maize were it not for the accompanying text (Fig. 14). The dates of this and other references are doubtful, and there has been cited no authentic mention of maize in Chinese literature definitely known to antedate the appearance of the Portuguese in the Orient in 1516. But its frequent mention in the literature of the sixteenth century, and the absence of any definite information as to the manner of its introduction, indicate long

acquaintance with it; and the occurrence in Chinese varieties of certain vegetative, floral, and endospermic characteristics not known in other varieties, points to a long period of isolation. The American origin of the plant is seldom questioned today, but this does not preclude the remote possibility of its introduction into Asia before 1492.[1]

At the time of the discovery of America, maize was the staple food plant of both continents and undoubtedly the central factor of aboriginal civilization. The wonder that it excited in the early explorer, and the rapidity with which it found a place in the economic life of the Old World after its introduction early in the sixteenth century, are strong indications that it was previously unknown there. These are ably supported also by the botanical evidences, all of which show that the nearest relatives of maize were undoubtedly of American origin.

The high degree of maize culture practiced in ancient Mexico and Peru has led to the belief on the part of some historians that the plant had a double origin, one strain being evolved in North America and the other in South America. An additional basis for this idea is found in the fact that pod corn, which was once believed to be very near the wild form in character, has been reported from localities as widely separated as Paraguay and the Rocky Mountains.

[1] The evidences on all sides of this interesting question are reviewed by Collins (22) in connection with the description of a peculiar variety of corn recently discovered in China. The endosperm of this variety is "waxy"; the leaves stand erect and assume an asymmetrical arrangement; and the silks precede the ends of the husks in their emergence from the leaf sheath subtending the ear.

But there seems to be no necessity for the radical assumption of a duplicate origin, and the botanical evidence of such an occurrence is entirely lacking. All kinds of maize, from all parts of both continents, are alike in all fundamental characteristics. Pod corn frequently appears by regressive variation in any variety and is no longer believed to be the bearer of unchanged prototypic characters down to the present.

The fragmentary history of the early migrations of aboriginal tribes, and the evolution of the vocabulary related to maize and its associations, point to a single origin in some central location. Indian literature is never a very dependable source of exact information, but many legends tell of the introduction of maize culture from tribes in the general direction of Central America. One elaborate myth of the Mayas, of the low, forested foothills of Yucatan and Central America, tells how certain earthly deities, or supermen, gave to the barbarian tribes the seed of maize and taught them its culture and uses.[1] This seems to be the most nearly scientific account of this event that the Indian has ever given the white man. In the versions of this tradition in most tribes, the supernatural figures so prominently as to destroy or obscure any atom of fact that may originally have been present, but the geographical location of the incident is probably the least likely to be perverted in the telling.

As to the exact locality that was the birthplace of the species, there may still be room for controversy; but the information now at hand points suggestively to the plateaus and foothills of Central America and

[1] See pp. 199–200.

southeastern Mexico (Fig. 8). A plant originating in this region, and soon becoming dependent upon cultivation for perpetuation and improvement, might reasonably be expected to attain its greatest prominence in the more favorable agricultural regions of Peru and central Mexico.

The claims of other places are not without foundation. Certain localities in the Andes have as favorable ecological conditions as those of Mexico and Central America, and Indian traditions might well be disregarded if inconsistent with more reliable data. But against this stands the limited range of teosinté, which has until recent years been uninfluenced by man, and has about the same distribution as should be expected of maize, were it not a useful plant.

CHAPTER IV

BOTANICAL ORIGIN

Maize stands almost alone among the cereals as a cultivated plant whose wild prototype is unknown. For most of our common cultivated plants there is a corresponding wild form, which, on being brought under cultivation, gives promise of resembling its cultivated relative, and toward which the cultivated form tends to revert on its escape from cultivation. But no plant has ever been found exhibiting such relationship with maize, and it has been an interesting problem for the botanist to build a bridge of theory from modern maize back to the point where its relationships are evident.

Sources of information.—There is available no direct information as to the nature of this interesting cereal previous to the last four-and-a-half centuries. How much of its evolution was due to primitive agriculture, and how much merely to natural conditions, we have no means of knowing. In fact, it would be difficult to say just when man's activities might cease to be called an element of natural environment and begin to be dignified with the name *agriculture*. At any rate, if man was present at the birth of the species, he left of the event no dependable record. The vagueness of most of the Indian myths on this point, and the promiscuous mingling of the natural and the supernatural, indicate much more imagination than observation.

In the absence of any direct evidence, then, we must have recourse to the circumstantial. For the solution of our problem, we may accept any theory that is consistent with facts; we must reject all that are out of harmony with facts; and our discrimination among the consistent explanations must be guided by what seems reasonable, and by the extent to which each theory has made use of all the available data.

The information from which our theory is to be deduced is not so extensive in this instance as in the case of many other plants, but it is sufficiently significant to warrant some definite conclusions.

Geology and archaeology give us practically no clue to the mystery. Only a few fossil remains of maize have been found,[1] and they are practically identical in nature with the living plant. Owing to the Indian custom of burying food with the dead, and to the abundance of the grain around Indian settlements, an enormous amount of material has been collected from tombs, buried huts, and the charred remains of camp fires.[2] The structures left by the Mound Builders of the Mississippi Valley, and the tombs of ancient Peru, have been especially fruitful sources. But not a single specimen has ever been found embodying any characteristic not present in the living plant.

[1] These are discussed by Collins (31).

[2] Much of the material that has been dug up from Indian ruins owes its preservation to its having been charred by fire. These ears were doubtless, in many instances, the small ones that had been overlooked in husking, or rejected as too insignificant to harvest. When the stalks were later used as fuel, the ears were often only partly burned. It is probable, too, that small, or partly decayed, ears that had been husked were at times used for fuel and only partly burned.

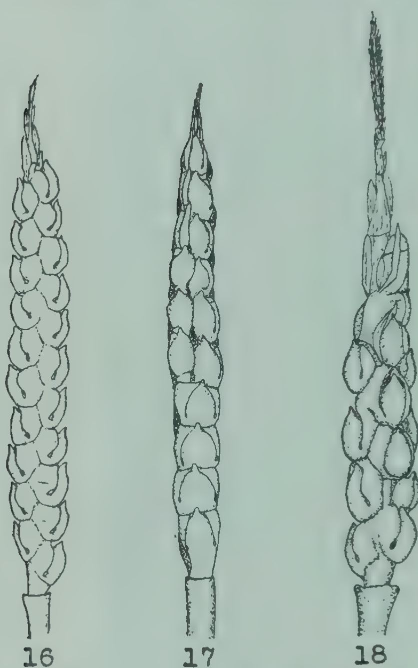
Maize is one of the most variable of the cereals; and this variability finds expression not only in the existence of an endless number of agricultural strains, but also in the sporadic appearance of anomalies. Many of these freaks seem to embody imitations of lost ancestral characteristics. But mutations may be either progressive or regressive, and the occurrence of these teratological forms cannot be used as evidence of the course of evolution, unless we have other proof that they are returns to remote ancestral conditions. Moreover, we must avoid the common error of assuming that a particular characteristic under consideration is regressive merely because it is associated in the same individual with other characteristics in which reversion is evident.

The methods of civilized agriculture have failed to do more than indicate the general trend of evolution in the plant. Breeding has eliminated a few superfluous organs, increased size and vigor, and concentrated the fruit into one or only a few ears; and these elements of specialization are probably a continuation of the process that nature and the Indian have been promoting for ages. The genetic researches on maize in the past twenty years have disclosed much of the evolutionary significance, and shown much about the order of appearance of many of the plant's most striking characteristics, but these methods have really done little toward indicating the connecting links between maize and its past. One of the confusing elements that have entered into the problem has been the suggestive appearance of the hybrids between maize and teosinté (Fig. 15). With proper manipulation, these hybrids may be made to show in the form of the ear a graded series of steps between maize

FIG. 15.—A hybrid between maize and teosinté. In habit this plant closely resembles pure teosinté.

and teosinté (Figs. 16–18). But these are the result of blended effects in hybrids, and not steps in an evolutionary series.

In both the vegetative and floral structures of maize, there have been disclosed, by histological methods, numerous rudimentary organs. From their behavior during the development of the plant, we believe these to be the remnants of parts that have ceased to function in past generations, and not the forerunners of parts that are to be. Many of the anomalies occurring in corn result from the functioning and full development of these vestigials. Such occurrences are to be regarded as true reversions.



Figs. 16–18.—Pistillate spikes of a first-generation hybrid between maize and teosinté.

A detailed morphological examination of Zea, in comparison with Euchlaena and Tripsacum, and taking into consideration the rudimentary organs and significant anomalies of the three genera, shows a remarkable similarity in structural plan, and furnishes a definite basis for working out the true phylogenetic relationships. A superficial view of characteristics, however, promises only a precarious basis for philosophic consideration.

The evolution of maize.—Since the introduction of the maize plant to science, many attempts have been made

to explain logically its botanical origin. Some of these explanations are clearly defective, but others are more consistent with facts. Each is to be considered a reflection of what was known of the plant and of the principles of evolution at the time at which the theory was proposed.

Much time has been spent in an unsuccessful search for wild maize. No one seems ever to have considered seriously any of the oriental species of the Tripsaceae as the wild progenitor; geographical separation and significant botanical differences indicate only a distant relationship. In the discovery of teosinté it seemed certain that wild maize had been found. The general habit of the plant, and many details of stem, leaf, and inflorescence, are suggestive of maize; and the scientific literature of that day includes references to teosinté as wild maize. But this idea has long ago been abandoned by most investigators.

Burbank was confident of this relation between maize and teosinté, and some of the latest authentic expositions of his work figure a fine ear of yellow dent corn by the side of its alleged pigmy ancestor, the "ear" of teosinté.[1] His followers go still farther, and picture

[1] A recent dissertation of this type by Robert H. Moulton, in the magazine section of the (St. Louis) *Post-Dispatch*, was given wide publicity by a review in the *Literary Digest* for July 9, 1921, and in one or two subsequent minor articles. Here it is alleged that, starting with wild teosinté in 1903, Burbank had, by selecting for eighteen generations, produced maize. The layman will doubtless hail this as a notable addition to the long list of Burbank's vegetable "creations." But the figures accompanying this article, like the color photographs included in certain publications of the Luther Burbank Society, indicate that the plant with which Burbank started was not teosinté at all, but *a hybrid between teosinté and maize.* Mass selection, intelligently carried out on the descendants of this hybrid, might reasonably be expected to result in a plant approaching maize in form. And an approach to

in graphic terms the imaginary "creation" of maize in past ages at the hand of some Montezuma Burbank, by the selection of favorable variations of teosinté. But, in spite of the popular following that this kind of logic may win, it becomes a mere jumble of imagination when measured by scientific standards.

Teosinté and maize are both highly specialized, but in different ways; and teosinté is far too highly specialized in some ways to be logically considered the ancestor of maize. No one dealing with pure strains by carefully guarded methods has ever been able to show, as a result of cultivation or selection, any tendency for teosinté to become maizelike or of maize to revert to teosinté.

A little more than thirty years ago, it was discovered that the natives of some parts of Mexico had a peculiar kind of corn known as "maiz de coyote." This variety had many apparently primitive characteristics, and at least two American botanists[1] described it as wild maize; but further investigation showed that its synthesis by crossing

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maize is really all that Burbank accomplished, for the superior forage properties claimed for the new "corn," and the photographs of the final form, show that many of the characteristic features of teosinté have not been eliminated from the hybrid by the selective process. That changes have been wrought in the plant cannot be denied, and the new form may well be the superior of teosinté as a forage plant; but the experiment affords not an atom of fact concerning the ancestry of maize. The loophole in this experiment is in the nature of the plant used as its basis; nothing is said as to the source from which it was obtained, and the only description given, namely, the photograph, indicates that it was not what it was thought to be during the experiment. If we wish to get merely a new useful *plant*, no special attention need to be paid such things as the exact origin of our material; but if we are seeking a new *principle*, such details are of fundamental importance.

[1] Watson (148) and Harshberger (74).

maize and teosinté and back-crossing with maize had often been accomplished by certain Mexican botanists.[1]

When the supposed wild maize was found to be a mongrel, it was conceived, by some twist of logic, that maize might have arisen as a hybrid between teosinté and some other grass.

One theory pictured the other parent as a superior form of teosinté that had been produced by cultivation.[2] But the necessity for this indirect method of origin has never been made clear, and the theory has gained little support. It would be as easy, and much more direct, for teosinté to throw off immediately the mutant maize as to produce a mutant which would hybridize with the parent species and produce maize.

According to another form of the hypothesis of hybrid origin,[3] maize originated in a cross between teosinté and some unknown grass having the general character of pod corn. But if this unknown grass had the general characters of pod corn, it would itself have had the general characters of ordinary maize, and the hybridization would have been unnecessary. Since the question of the origin of maize has been rather generally disregarded in recent years, except by those supporting the theory of hybrid origin, this idea has held a more prominent place than it merits. But many have accepted it with reluctance as being the only explanation having a prominent place in the literature.

This theory is illogical and unnecessarily imaginative, but it is also insecurely founded morphologically. It depends largely upon the predicated intermediate position of maize between the highly specialized teosinté

[1] See Harshberger (75). [2] *Ibid.* [3] Collins (24).

and the more simple pod corn. But a better morphological analysis than was available when the theory was first proposed shows less difference in specialization than was formerly supposed; and the definition of pod corn is determined more by the needs of the theory than by any exact identity. Hybrids between pod corn and teosinté have never been shown to give the significant evidence that would be expected under the assumed conditions. With the recognition of these shortcomings, the chimerical hypothesis fails. The idea came into being as scarcely more than a guess in answer to a question, and the facts and fancies that have been marshaled in its support fall far short of its substantiation.

The clearest and most reasonable deduction from the facts at hand is that Zea, Euchlaena, and Tripsacum descended directly and independently, in so far as hybridization is concerned, from a common ancestor now extinct. No morphological feature, genetic peculiarity, or historical fact is known to introduce any factor of inconsistency, and the theory is reasonable, orthodox, and simple.

Certain other genera of grasses very probably had the same origin as these three, but more or less artificial criteria of classification have thus far relegated them to a neighboring, and presumably more remotely related, tribe, the Andropogoneae.[1]

[1] It is unfortunate, for the cause of morphology, that monoecism was adopted as a unifying characteristic in forming the Tripsaceae. Elsewhere in the Gramineae, as in Poa, Eragrostis, and the Chlorideae, even dioecism is not given such significance, and it is evident in the Tripsaceae that monoecism has arisen independently in different genera. A thorough morphological study of the Andropogoneae may ultimately show that maize and the sorghums represent one branch, and Tripsacum, Euchlaena, and Rottboellia another, of the descendants of some common stock. The oriental Tripsaceae constitute almost a separate tribe.

The prototype of maize.—The similarities in structure among these three American genera of the Tripsaceae make possible a consistent mental picture of the hypothetical ancestor of all of them. If, in individual representatives of these three respective genera, the rudimentary organs whose vestiges are present could be induced to make full development and resume their former functions, the three forms would converge toward a single one resembling the prototype.

The common ancestor was probably a herbaceous perennial. Its branching culms arose in tufts from a mat of short rhizomes, and the ramifications branched again and again at all but the uppermost nodes. Diffuse panicles of paired spikelets terminated all the branches. Each spikelet had two perfect flowers. The pistil had two styles.

Embodied in this species was a tendency toward specialization by the abortion of parts. This has found its best expression in the evolution of monoecism. The manner in which monoecism came about differentiated Tripsacum from Euchlaena and Zea. The latter two differed from each other in the manner of the reduction of their panicles. With the adoption of the annual habit, the rhizomes disappeared, and the tuft of culms was reduced to a single axis and its branches.

At the climax of evolution in maize, the process of abortion has eliminated all the lateral branches except that bearing the ear, and has left but two inflorescences. A detailed discussion of the possible steps in these processes can be most advantageously included in the morphology of the various organs of the plant.

CHAPTER V

STRUCTURE AND GERMINATION OF THE SEED

In size, shape, color, and external form, the grain of corn is variable, but it constantly possesses three fundamental parts: a tough, dry, membranous covering; an embryonic corn plant; and a reserve food supply (Fig. 19).

The protective covering consists of the seed coat proper and the matured wall of the ovary; it is the testa and the pericarp combined. At one end of the grain the pericarp is marked by the minute, beaklike base of the silk that was attached during development. At the other end it merges into the chitinous pedicel by which the grain was attached to the cob.

A large part of the seed is made up of the endosperm. The cells of this tissue are richly stored with food materials for the nourishment of the young plant.

Imbedded in one side of the endosperm, and in contact with the seed coat, is the embryo. Structurally, it consists of a short central axis terminated above by the plumule and below by the radicle, and bearing from its middle portion the large cotyledon.

The plumule is the bud from which are to develop the stem and leaves of the seedling. It is completely inclosed in the firm, cylindrical coleoptile, or plumule sheath.

The radicle consists of the primary root and its cap and the inclosing coleorhiza, or root sheath.

The cotyledon is doubtless the first leaf of the embryo. It is laterally attached to the central axis, which it partly

surrounds with its two lateral folds. The portion of the cotyledon in contact with the endosperm is the scutellum.

The middle portion of the embryonal axis, to which the cotyledon is attached, is the very short stem of the embryo. Arising from it are the primordia of two or more secondary roots. A meristematic area almost opposite the cotyledon probably represents a rudimentary cotyledon, the second embryonal leaf. This is the equivalent of the epiblast of some grasses.[1]

Viability.—The seeds of maize vary greatly as to term of viability. They are capable of germination as soon as mature, no after-ripening process or other period of dormancy being necessary. In warm, moist weather even immature grains often sprout while still on the ear inside the husk, and very immature grains may be dried and later made to germinate.

Retention of vitality by the ripe seeds depends largely upon

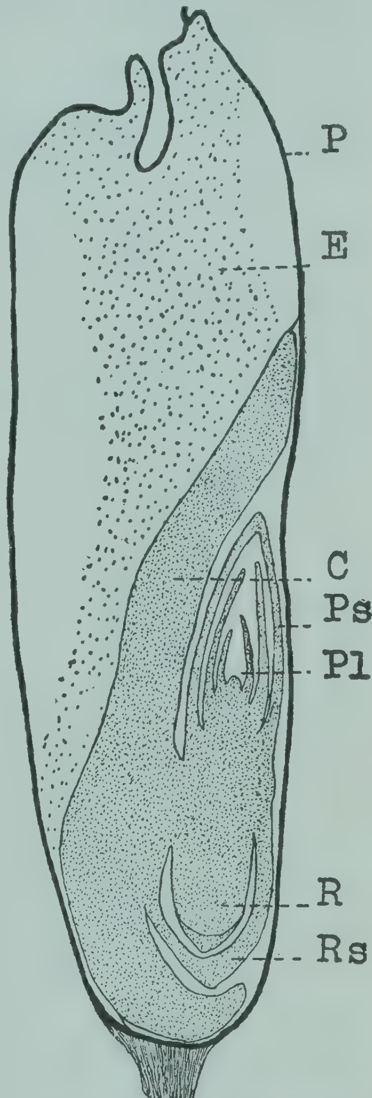


FIG. 19.—Longitudinal section of a grain of dent corn. *P*, pericarp; *E*, endosperm; *C*, cotyledon; *Ps*, plumule sheath (coleoptile); *Pl*, plumule; *R*, root; *Rs*, root sheath (coleorhiza).

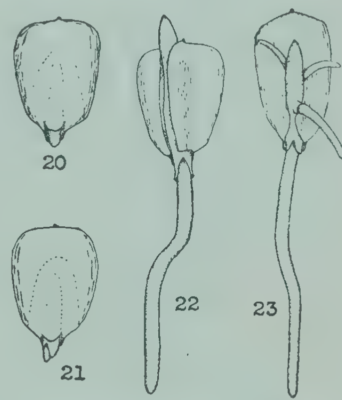
[1] A more detailed account of the embryo will be found in chap. xix, where its development is treated.

the variety, but chiefly upon the conditions under which the seeds are matured and to which they are subjected after maturity. Most grains of corn retain their vitality for two or three years, and good results are sometimes obtained from seeds eight to ten years old if they have been kept dry. But exposure to cold and moisture, or frequent changes in moisture content, may render them incapable of germination the year following maturity. Seeds, too old to grow under ordinary conditions prevalent in the field, may often be made to germinate under optimum conditions of moisture and temperature.

There are no authentic cases on record of the germination of seeds of maize more than ten or twelve years old, and twenty-five years might reasonably be set as the maximum period of viability. Newspaper stories of the germination of seeds of maize that have been dug from Indian mounds are to be regarded as examples of sensational journalism.

Near the end of the term of viability, the final indication of life takes the form of abnormal germination, due to the inability of the plumule or of the root to rupture the pericarp. Sometimes both fail, and only a secondary root appears. At times, secondary roots, unable to break out of the pericarp, may grow to a considerable length, winding themselves around the contents of the seed. This is especially likely to happen when immature seeds germinate on the cob while yet inside the husk. These abnormally emerging plants are unable either to secure moisture or to make food, and soon die. Thus, seed germination is seen to be complicated by the fact that the seed is never normally free from the rest of the fruit.

Germination.—When a viable grain of corn is surrounded with proper conditions of moisture, temperature, and air, germination proceeds by an orderly succession of definite steps. The whole fruit imbibes water and swells, the increase in weight often being as much as 100 per cent. In thirty-six to sixty hours, the primary root bursts the pericarp, breaks out of the coleorhiza, and makes its way downward (Figs. 20–23). A few hours later, two or more secondary roots make their appearance from the node to which the cotyledon is attached. Because of structural peculiarities, these are directed upward at first, but after their emergence they respond to gravity and start downward. While the secondary roots are developing, the enlarging plumule also breaks through the pericarp and starts upward. The coleoptile remains intact, however, until growth has brought its tip to the surface of the soil. This plumule sheath is of great importance to the plant in furnishing a protection for the tender foliage leaves and providing a sharp spike to open the way through the soil.



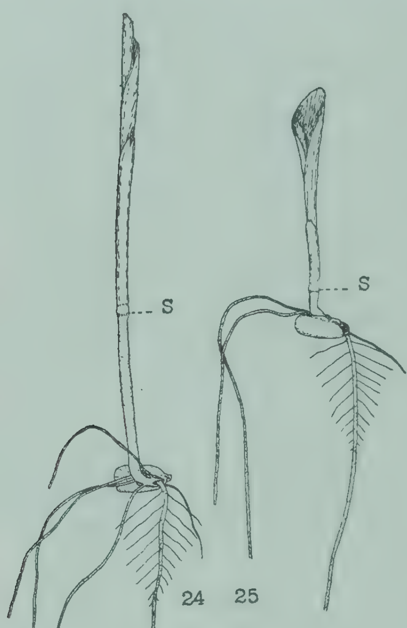
FIGS. 20–23.—Steps in the germination of a grain of corn.

Before the rupture of the coleoptile,[1] it and the plumule usually increase ten to twenty times their original length, but the greater part of the elongation responsible for bringing the leaves above the surface

[1] The exact structure of the parts of the embryo here discussed is a point still in controversy, but this interpretation seems to have the weight of evidence on its side. For a summary of the arguments on various phases of this question see the writer's paper (158).

is in the internode of the epicotyl immediately below the coleoptile.

The depth to which a grain of corn may be planted, with fair promise of successful germination, depends upon the ability of this internode to elongate. If the seed is planted so deep that the foliage leaves break out of the coleoptile before reaching the surface of the soil, the plant usually dies, or is much retarded in its development. The same fate befalls it, even when the seed has been planted at less depth, if growing conditions are so unfavorable that the energy stored in the seed cannot be used economically in germination. For this reason, corn may be planted deep when the soil is warm and comparatively dry, but must be planted at less depth when the soil is cold and wet.[1] The seeds of some varieties are so weak that an inch is the maximum depth to which they may be planted under the most favorable conditions; but the Indians of the arid regions of the southwestern parts of the United States have varieties that can be planted 18 inches deep.[2]

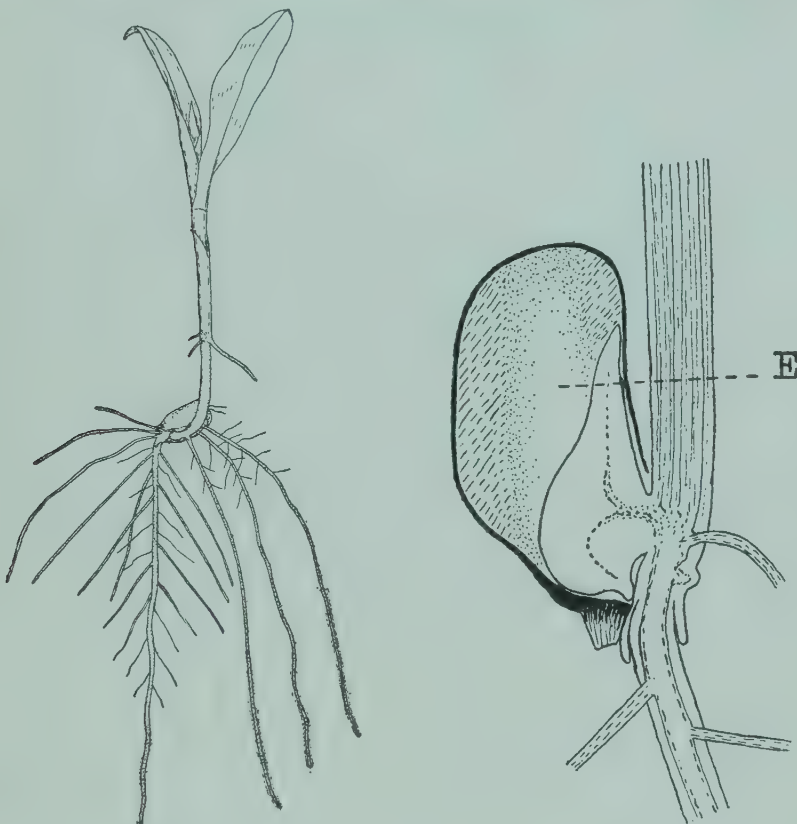


FIGS. 24, 25.—Effects of deep and shallow planting. *S*, coleoptile (plumule sheath). The one grain was planted 5 inches deep; the other was barely covered.

[1] The differences in the proportions of parts of the plant, due to deep and to shallow planting, are shown in Figs. 24 and 25.

[2] Collins (27).

As this elongated internode of the epicotyl reaches its ultimate length, roots spring from the node above it. These, with others arising from the higher nodes, are



26 27

FIGS. 26, 27.—Fig. 26, seedling at the end of germination. Fig. 27, longitudinal section of germinating grain, showing at *E* the region in which the endosperm is being digested by enzymes secreted by the cotyledon.

destined finally to become the main part of the root system of the plant. The primary root, and the roots arising from the first node of the seedling, serve their function chiefly during germination.

Because of its double vascular system, the ruptured coleoptile is often split into two lobes at the top. This

has been taken to indicate that the coleoptile is the homologue of the ligule of the vegetative leaf, inasmuch as the ligules of many grasses have a bifid apex.[1] But this theory has generally been abandoned in favor of the idea that the coleoptile is a modified foliage leaf.

Meanwhile, the cotyledon has been absorbing the endosperm and transferring it into the growing tissues of the seedling (Fig. 27, p. 37). The surface of the scutellum next to the endosperm contains glandular cells which produce the enzymes that digest the endosperm.

When the roots of the seedling have established connection with a permanent supply of moisture, and the foliage leaves are expanded and ready to begin their functions, germination may be said to be finished (Fig. 26.) At about this time, or a little later, the last of the food stored in the endosperm is consumed, and the new plant begins its independent existence.

[1] Worsdell (172).

CHAPTER VI

ANATOMY AND PHYSIOLOGY OF THE STEM

In the structure of its vegetative parts, the maize plant is very similar to the other grasses; and the grasses, as a group, are characterized by only relatively slight modifications of the fundamentals common to all the higher flowering plants.

The individual plant consists of two well-defined parts: the roots and the aerial shoot. The latter is made up of the stem and the leaves. The roots hold the plant in position and obtain water and minerals from the soil; the leaves are chiefly responsible for the elimination of water and for the synthesis of organic food materials. The stem supports the leaves and flowers and affords a line of transportation between leaf and root.

At a definite time in the life-cycle, the staminate inflorescence appears as the metamorphosed terminal portion of the main shoot, and it is soon followed by one or more pistillate inflorescences terminating lateral branches. The pistillate inflorescence becomes in time the mature ear. The basal branches of the plant, usually known as *tillers* or *suckers*, have structurally the same origin as the ear-bearing branches, but they early take root and make varied development. Some grow as tall as the main stem and resemble it in all details; at other times, they become nothing more than short vegetative shoots; and between these two extremes various gradations occur. The variable inflores-

cence of the suckers is significant and will be described later.[1]

The unit of structure.—The stem is marked into definite segments by the occurrence of nodes, at each of which is attached a leaf and, in most instances, a bud or a branch. An internode, together with the leaf at its upper end, and the bud at its lower end, constitutes a *phytomer*, the unit of structure of the shoot (Fig. 34).

Any single phytomer shows the fundamental anatomical characteristics of the whole vegetative shoot. The upper internodes are straight and nearly cylindrical. The buds at the upper nodes are small and poorly developed, or sometimes represented by only a meristematic region. The internode immediately above each ear is deeply grooved on one side and bent concave to the ear. The internodes below the ear are straight, but often flattened; a groove on one side of each of these contains the bud. These grooves are alternately arranged on succeeding internodes, corresponding to the alternate arrangement of the leaves and buds.

Minute anatomy.—The arrangement of the tissues in the typical grass stem is favorable to the development of great length and rigidity, combined with lightness and small girth; but the maize plant is far less successful than many other grasses in attaining extreme proportions in the dimensions of its stem. It has a relatively thick, heavy stem, made heavier by its content of a solid pith, a characteristic which it shares with few other grasses.

The epidermis of the stem is much like that of the leaf. It is made up of rectangular cells, whose walls,

[1] See chap. xiv.

unlike those of the foliar epidermis, are hardened with deposits of silica. The stomata are similar to those of the leaf.

Inclosing the other parts of the culm is a thick, hard shell composed of the silicified epidermis and a layer of sclerenchyma. The pith is traversed longi-

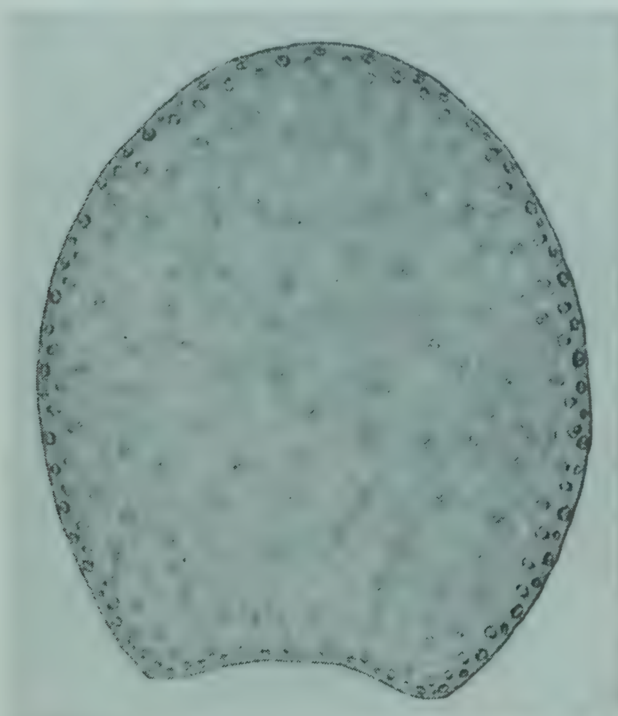


Fig. 28.—Cross-section of an internode of the stem

tudinally by numerous vascular bundles, which serve as avenues of transportation and as tensile reinforcement, the latter function being correlated with their tendency toward a peripheral distribution (Fig. 28).

At the nodes, the pith is usually more compact, and the vascular tissue less regular than in the internodes. Some of the bundles pass directly from one

internode into the next, and some are diverted into the leaf and bud; but many of them anastomose, or show other irregularities.

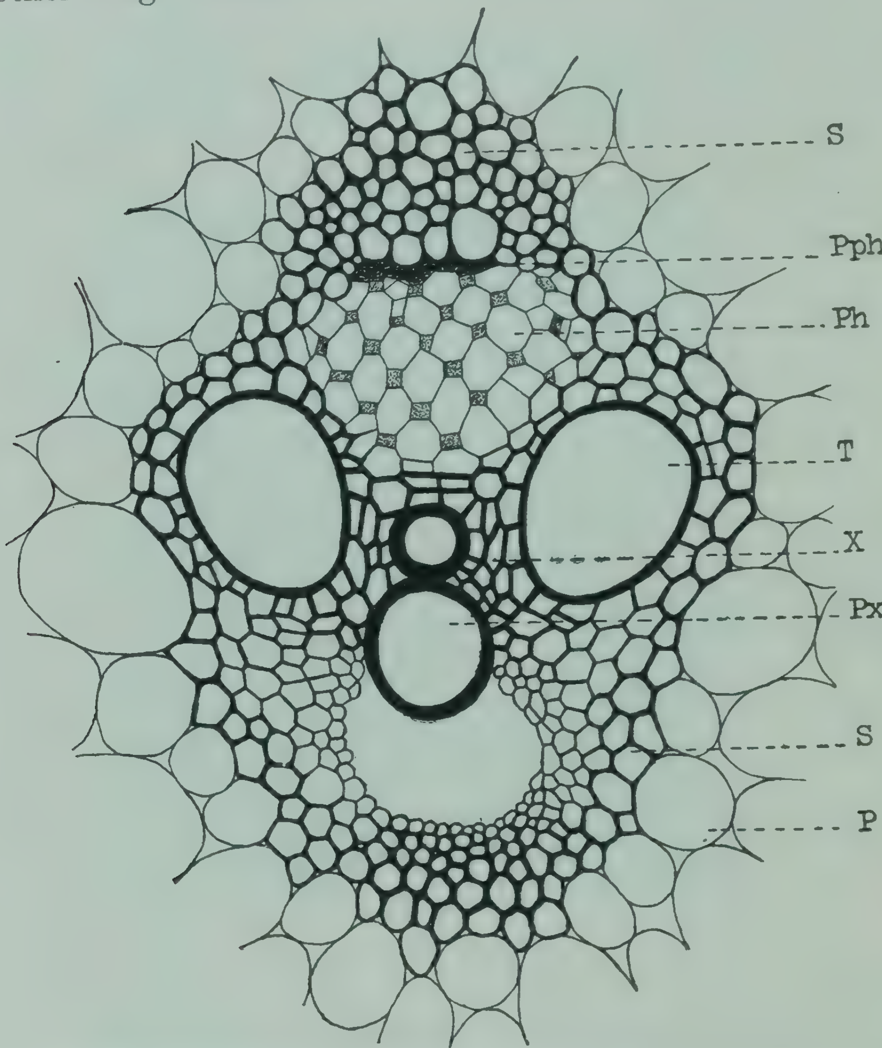


FIG. 29.—Section of a well-developed, centrally located vascular bundle. *S*, sclerenchyma; *Pph*, protophloem; *Ph*, phloem; *T*, trachea of the xylem; *X*, tracheids; *Px*, protoxylem; *P*, parenchyma.

The vascular bundle.—In a transverse section of a mature and well-formed vascular bundle (Fig. 29), the most prominent feature is a pair of large tracheae.

Connecting these is a group of xylem elements, and at one side of the latter is a large air space containing one or more spiral or annular vessels. On the other side of the xylem is the phloem, made up of large sieve tubes

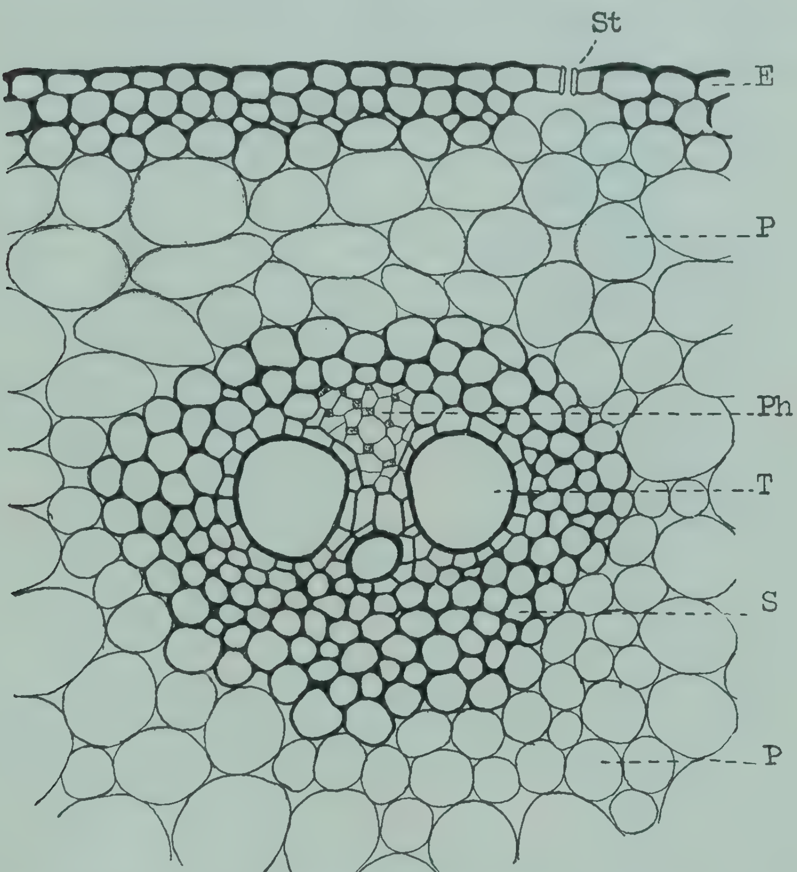
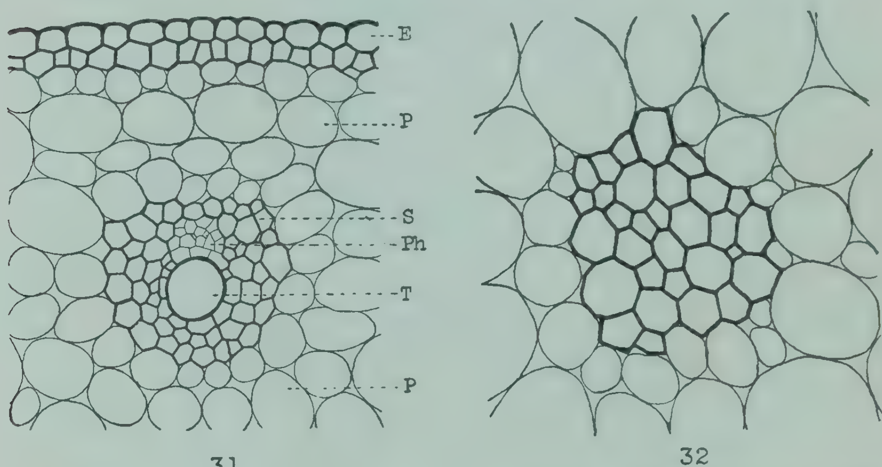


FIG. 30.—A vascular bundle near the periphery of the stem. *E*, epidermis; *St*, stoma; *P*, parenchyma; *Ph*, phloem; *T*, trachea; *S*, sclerenchyma; *P*, pith.

and small companion cells, all more or less regularly arranged. In the arrangement of all the bundles there is a tendency for the phloem to be turned toward the outside and the xylem toward the inside of the stem, but this tendency is less evident near the center than toward

the periphery. The vascular bundles are surrounded by sheaths of sclerenchyma, whose cells are fairly uniform except in the neighborhood of the oldest part of the phloem, where they are often much enlarged. This sheath is responsible for the fibrous nature of the vascular bundle.

Development of the stem.—The formative period of development in the main shoot of the corn plant is of



FIGS. 31, 32.—Fig. 31, a vascular bundle very much metamorphosed. *E*, epidermis; *P*, parenchyma; *S*, sclerenchyma; *Ph*, phloem; *T*, trachea. Fig. 32, a vascular bundle represented by only a strand of sclerenchyma.

short duration. In an ordinary seedling, 5 to 10 inches tall, all the phytomers and the main branches of the terminal inflorescence have often been formed. The first few phytomers reach maturity without any considerable increase in length of thickness, the number of these varying with growing conditions and depth of planting. But the size of the succeeding mature units is quickly increased until a maximum diameter is reached in the first or second internode wholly above the ground. Above this the succeeding mature internodes are thinner

and longer. The result is a stem tapering gradually toward the tassel and abruptly downward to the cotyledonary node (Fig. 33).

A young internode is capable of increasing in both length and thickness for a time, but growth in both directions soon reaches a limit. Increase in thickness is accompanied by an increase in the number rather than the size of the vascular bundles. A new bundle arises as a longitudinal strand of procambium in the parenchyma of the young stem, and a protophloem and protoxylem are soon formed. These temporary forerunners of the permanent vascular elements are of great importance while the stem is elongating; but, as the ultimate length of any part of the internode is reached, the permanent xylem and phloem in that part are laid down and matured. The meristematic tissue present between the xylem and phloem, in early stages of development, functions as such for only a short time; its cells soon cease to divide, and mature as xylem

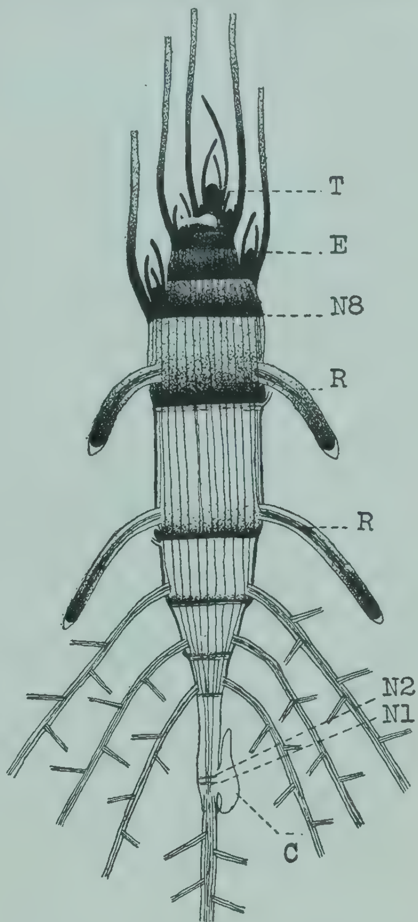


FIG. 33.—A diagrammatic longitudinal section of a young maize plant, showing regions of development. The density of shading shows relative potentiality for further development. *T*, terminal bud; *E*, lateral bud (ear); *R*, buttress root; *C*, cotyledon; consecutive nodes, beginning with the lowest, are indicated *N1*, *N2*, etc.

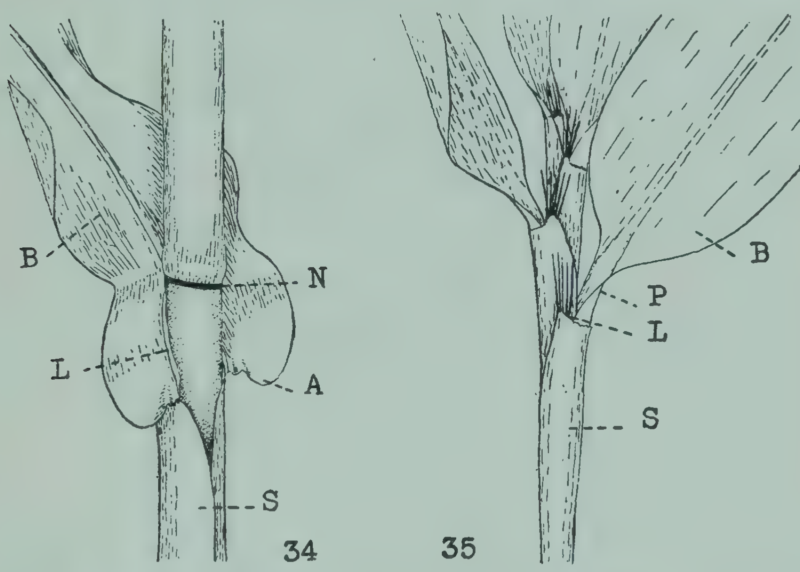
and phloem. This is responsible for the uniformly limited size of the vascular bundles. In the mature bundle, the protophloem remains as a thin layer of disintegrated cells between the phloem and the bundle sheath; the annular and spiral vessels are the remnants of the protoxylem (Fig. 29).

Elongation of the internode continues long after the ultimate diameter has been reached. In any internode, the oldest part is at the upper, and the youngest part at the lower end; and a region of embryonic tissue in the latter position is responsible for increase in length. This segment of growing tissue above each node would constitute a weak place in the stem were it not for the support provided by the surrounding leaf sheath. Even after all normal increase in length has ceased, this meristematic region is still present, and may resume activity if the stem be placed in a horizontal position. Under such conditions, the internode begins to elongate on the lower side, doing its individual part in an attempt to bring at least the terminal portion of the stem into a vertical position.

CHAPTER VII

STRUCTURE AND FUNCTIONS OF THE LEAF

The leaf consists of three distinct parts: the *sheath*, which surrounds and strengthens the meristematic part of the next higher internode; the *blade*, or *lamina*, leaving the stem near the node next above the one to which it is attached; and the collar-like *ligule*, attached



FIGS. 34, 35.—Fig. 34, parts of the leaf. *B*, blade; *N*, node; *L*, ligule; *S*, sheath; *A*, auricle. Fig. 35, the leaf of Arundinaria, one of the Bamboos, for comparison with that of maize. *B*, blade; *P*, petiole; *L*, ligule; *S*, sheath.

at the top of the sheath and closely surrounding the stem. The base of the lamina is extended into two auricles (Fig. 34).

The phylogenetic significance of the leaf of the grasses, and the homology between its parts and those

of the leaves of other plants, have afforded opportunity for much speculation, and unanimity of opinion does not prevail. The lamina is doubtless the equivalent of the structure elsewhere having the same name; the sheath is probably the homologue of the enlarged leaf base; and the ligule seems to be a modified pair of stipules.[1]

The blade of the leaf is a thin, flat, ribbon-like structure, tapering slowly from an auricled base to an attenuate tip. Support is provided by a firm midrib extending the full length. This is merely a thickened portion of the blade, made up principally of pith and sclerenchyma, devoid of chlorophyll, and traversed by numerous vascular bundles. Parallel to the midrib, and spaced at regular intervals, are numerous smaller veins, each having a single vascular bundle. These vary in size, every tenth to fiftieth one being much larger than the others. They seldom anastomose bodily, but frequent vascular cross-connections provide for lateral as well as longitudinal conduction. Most of the larger veins may be traced down the blade to the sheath, and down it to the node, where they enter the stem.

The lamina curves away from the stem in a graceful arch, and its wings display a gently undulating fulness. These structural features, with the ability of the sheath to twist slightly on the culm, give to the leaf an elasticity that does much to save it from injury in the wind.

Lobed leaves.—As the young leaf develops in the bud, there is a time when the two edges of the rolled structure are in contact with each other long enough for one or both to receive an injury sufficient to cause the develop-

[1] These homologies are suggested in a striking way in the bamboos, which have a short petiole between the sheath and the lamina (Fig. 35).

ment of a lobe on the mature leaf. Sometimes the leaf has a single lobe, but quite as often there are two. Consistent with their early origin, these lobes do not have the appearance of pieces mechanically split off the leaf, but their edges exhibit the marginal modifications of the epidermis of normal parts of the leaf.

The epidermis.—The epidermis of the leaf is made up of rectangular cells whose walls are wrinkled into

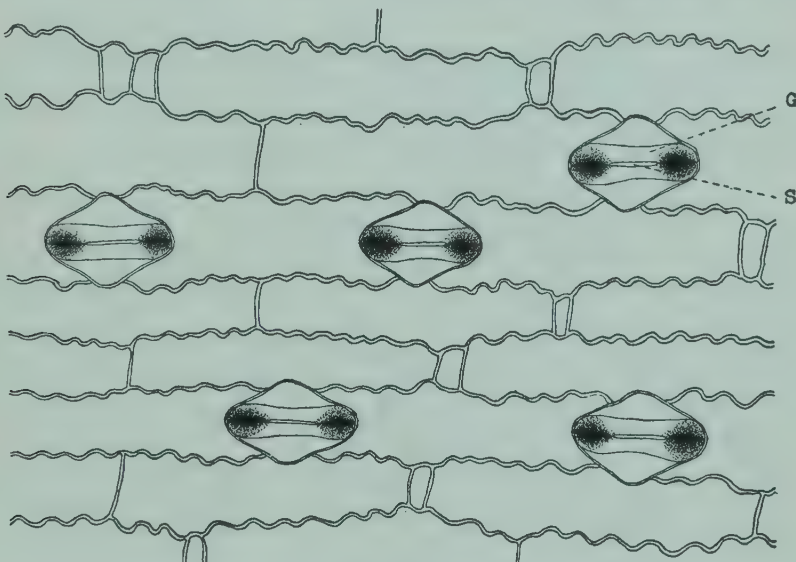


FIG. 36.—Portion of the epidermis of the leaf. *S*, stoma; *G*, guard cell

minute, undulating irregularities (Fig. 36). The stomata, which are arranged in parallel longitudinal rows, are somewhat more numerous in the lower than in the upper epidermis—about 60,000 to 100,000 occurring in a square inch of the former, and 50,000 to 60,000 per square inch in the latter. No reliable data are at hand as to the efficiency of the stomata in regulating transpiration.

The lower epidermis is glabrous, but the upper surface, and that of the sheath, may range from glabrous to velvety pubescent. The pubescence is made up of

minute, soft, unicellular hairs, each of which is a modified epidermal cell.

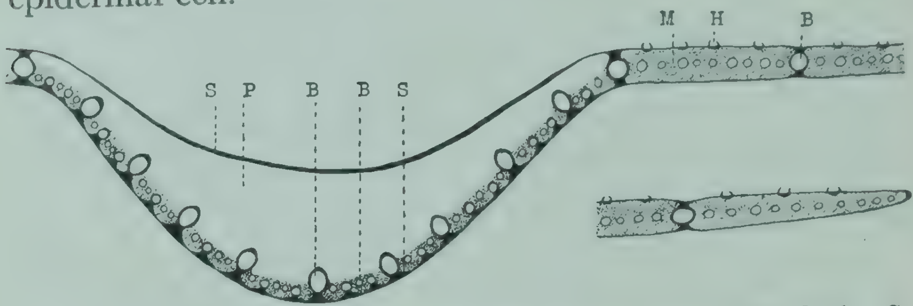


FIG. 37.—Diagram of a cross-section of the blade of the leaf. *S*, sclerenchyma; *P*, parenchyma; *B*, vascular bundle; *M*, mesophyll; *H*, hygroscopic cells with adjacent hairs.

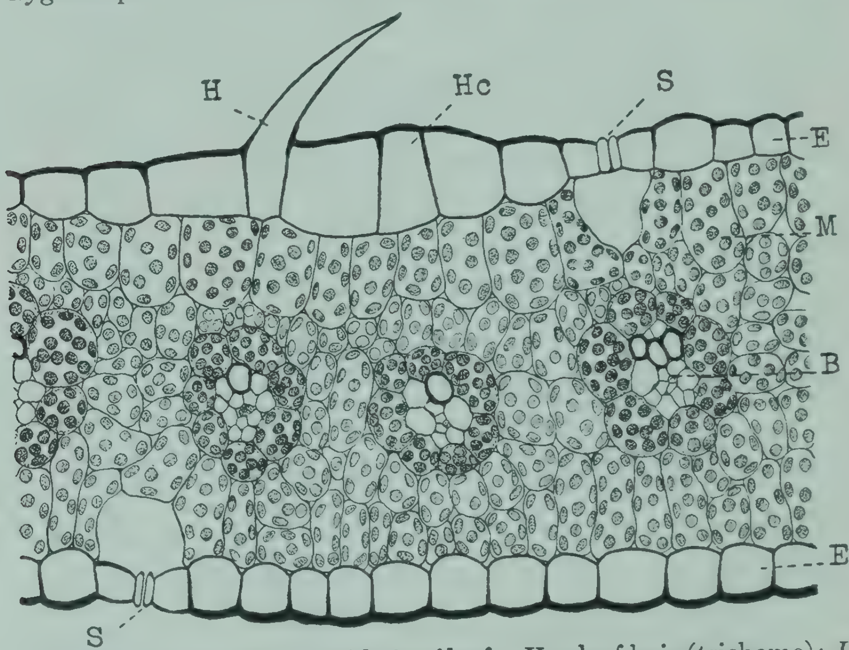


FIG. 38.—Cross-section of blade of leaf. *H*, a leaf hair (trichome); *Hc*, hygroscopic cell; *S*, stoma; *E*, epidermis; *M*, mesophyll; *B*, vascular bundle.

Color.—The midrib, auricles, ligule, and larger veins are yellowish or almost colorless. Other parts of the leaf show various tints and shades of green, the seat of the color being the chloroplasts in the cells of the mesophyll (Fig. 38). The development and retention of

this green color depends upon a proper environment. Plants that are exposed to too low a temperature, or to insufficient light, tend to lose their color; and the same effect may be produced by too much moisture in the soil, or by the presence of injurious substances, or the lack of necessary minerals, notably iron, in the soil.

Besides these effects of environment, there are certain occurrences, of an inherited nature, in which the plant assumes a similar appearance. Certain races have a recessive hereditary factor for the total or partial absence of chlorophyll, and inbreeding brings out albinos, or individuals with a reduced amount of chlorophyll.[1] Other varieties show a leaf variegation in the form of white, red, or yellow stripes.

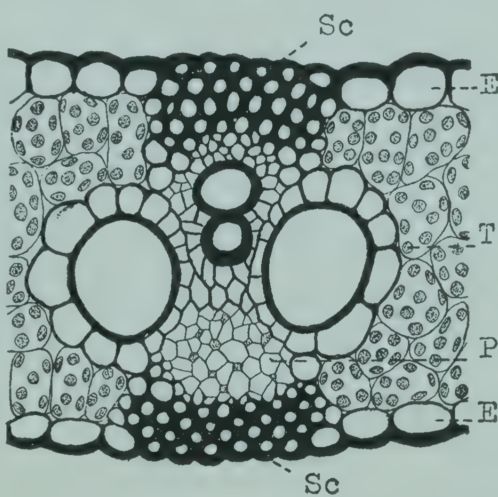
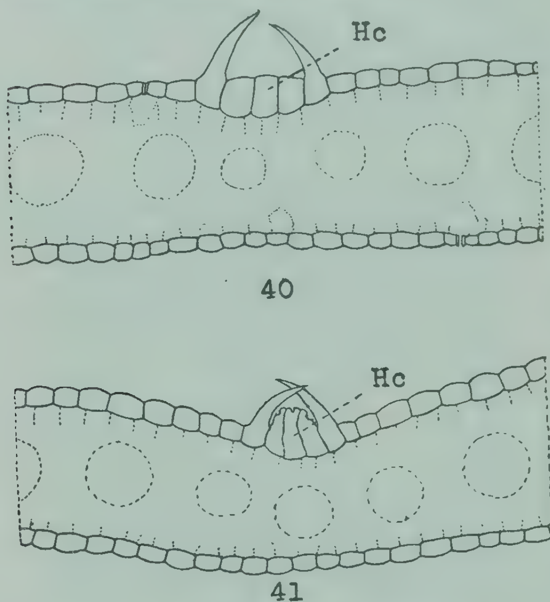


Fig. 39.—Section of the leaf through one of the larger vascular bundles. *Sc*, sclerenchymatous bundle sheath; *E*, epidermis; *T*, trachea; *P*, phloem.

Histology.—In cross-section, the leaf blade and sheath are much alike, the chief difference being in the thickness and relative amount of chlorophyll-bearing tissue (Figs. 37–39). The mesophyll consists of loosely arranged cells, irregular in shape. Beneath each stoma is a large intercellular air space. The vascular bundles are similar to those of the stem, although less regular in size and shape. The smaller bundles have a

[1] Lindstrom (105) and Miles (107).

sheath whose cells are filled with large prominent chloroplasts.[1] Others, especially the largest ones, are surrounded by heavy sheaths of sclerenchyma, which often extend to the epidermis and even produce prominent longitudinal ridges on the leaf sheath.



FIGS. 40, 41.—Fig. 40, section of a leaf well supplied with moisture. Fig. 41, section of a leaf suffering from excessive transpiration. *Hc*, the hygroscopic cells, which lose moisture and shrink, thus shortening the upper epidermis.

At regular intervals in the upper epidermis, occur longitudinal groups of hygroscopic cells. Under ordinary conditions, these are gorged with water, but when conditions are favorable for excessive transpiration, these cells shrink from loss of water and shorten the epidermis on the upper side, the combined effect of shrinkage in many such groups being to cause the leaf to roll up (Figs. 40, 41). When the leaf is rolled, the upper epidermis, and usually a part of the lower, is protected from the air. This behavior is probably quite as effective as the opening and closing of the stomata in regulating the loss of moisture. Since

[1] As noted by Kiesselbach (98, p. 189), the appearance of these cells in preparations stained by ordinary methods is very deceptive, the chloroplasts assuming a striking, abnormal arrangement.

the curving blade must straighten on rolling, the leaves have a characteristic erect position when rolled.

Most of the minute hairs constituting the pubescence of the leaf blade are arranged along these hygroscopic areas of the epidermis, and each hair curves over as if to protect the turgid cells. The function of these hairs is problematical. At first glance, it seems plausible that they prevent excessive transpiration by protecting the cells that lose water most readily. But, if they have any protective function in this way, they really permit greater transpiration in the long run, for it is through loss of water from the tissue that these hairs seem to protect that the leaf is enabled to roll up and protect itself from drying conditions.

The ligule.—The ligule is a membranous outgrowth of the epidermis. It fits collar like around the stem, and its chief function seems to be to prevent the entrance of water into the space between the sheath and the culm. One or more varieties of corn have been isolated by inbreeding, in which the ligules and auricles of the leaves are lacking.[1]

Metabolism.—Chiefly upon the leaf, and less upon the green parts of the stem, rests the responsibility of initiating the food-making process of the plant by synthesizing the carbohydrates, which become the basis of all food. From the air, which enters through the stomata and permeates the intercellular spaces of the green parts of the leaf, carbon dioxide is taken, and the vascular system contributes water, which has been brought up from the soil. These oxides meet in the chloroplasts, which, in the presence of sunlight and good

[1] Emerson (53).

growing conditions, synthesizes a carbohydrate, which is temporarily deposited in the cell in the form of starch. Oxygen escapes as a by-product.

The enzymes of the cell may readily change the carbohydrate from one form into another, some of these forms being soluble and others insoluble. In the soluble form, they may be transported through the phloem to other parts of the plant to be stored or used otherwise. Carbohydrates contain all the materials necessary for the formation of fats, but the details of the process by which this conversion is accomplished are unknown. From the water taken up from the soil, nitrates and other mineral compounds are selected and added to the carbohydrates to form proteins; but the synthesis of proteins also involves processes still wrapped in obscurity.

Transpiration.—In exposing its delicate mesophyll to the air for the absorption of carbon dioxide and the elimination of waste materials, the plant unavoidably brings about a favorable condition for the loss of water by evaporation. This loss is made up by the constant upward movement of water from the roots. The escape of water is probably not so effective in condensing dilute solutions of mineral salts as is sometimes supposed, the concentration of these being kept in a state of equilibrium by osmosis. Neither does this evaporation of water seem to be necessary to keep the plant cool. Transpiration is rather to be looked upon as an inadvertent necessity than as the performance of a function. To maintain proper relations with the atmosphere, the plant must pay the price in water. When that price is reasonable, it is paid, and the plant flourishes; when

it is too great, the plant protests by closing its stomata and rolling its leaves, and the active resumption of normal processes awaits better conditions.

Guttation.—The pressure exerted by the various forces responsible for the upward movement of water in the plant often forces water in the liquid form from the leaves when conditions are not favorable for evaporation. This process, known as *guttation*, explains the common occurrence of drops of water on the leaves of corn or other plants early in the morning.

CHAPTER VIII

BRANCHES OF THE SHOOT

Probably every node of the corn plant bears a bud or the meristematic rudiment of one. At some of the upper nodes, these rudiments are so small as to be practically indistinguishable from the embryonic tissue of the next higher internode, and many of the buds at other

FIGS. 42–44.—Fig. 42, a highly specialized ear-bearing branch. Fig. 43, an ear with leaf blades well developed on its husks. Fig. 44, an ear showing small secondary ears resulting from the development of buds in the axils of the husks.

nodes make such limited development as not to emerge from the leaf sheath; but one or more near the middle of the stem develop into ear-bearing branches, and those at the base of the stem often develop into suckers.

The pistillate branch.—Vegetatively, the ear-bearing branch is much like the main shoot; but its internodes are

so much contracted in length that the greatly enlarged and overlapping leaf sheaths form the well-known covering of husks (Fig. 42). In this branch, the uppermost internodes are short, and the lower ones progressively longer—a condition exactly opposite that prevailing in the main culm (Fig. 45). In many instances, the husks bear well-developed laminae and ligules; but these structures are usually greatly reduced or entirely lacking (Figs. 42, 43). The axis of this shoot is the same as the main stem in essential structure, but its

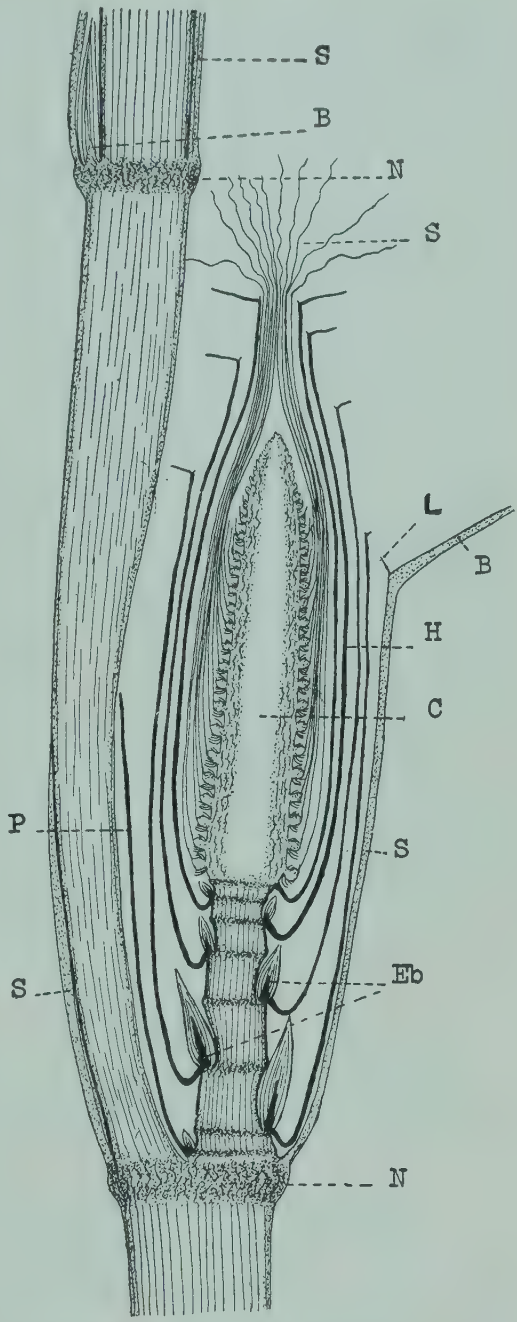


FIG. 45.—Diagram of longitudinal section of ear-bearing branch. *S*, leaf sheath; *B*, axillary bud, an undeveloped ear-bearing branch; *N*, node of the main axis; *S*, silks exposed beyond the ends of the husks; *L*, ligule; *B*, leaf blade; *H*, husk of the ear, a greatly enlarged leaf sheath; *C*, cob of the ear; *Eb*, secondary ear buds; *P*, prophyllum.

well-developed vascular tissue and the close proximity of its successive nodes give to its interior a tangled, tough, fibrous nature.

FIGS. 46, 47.—Fig. 46, a many-eared plant of one of the "prolific" pop varieties. Fig. 47, plant with basal branches (suckers).

In the axil of each husk of the ear is borne a bud, and some of these occasionally develop into small branch ears (Fig. 43). These, however, must not be confused with the branches of the ear of branch corn (Fig. 84, p. 107) nor with the abnormal branches sometimes found at the very base of the ear above the uppermost husk

(Fig. 82, p. 107). These latter occurrences are branches of the inflorescence proper and not separate axillary inflorescences.

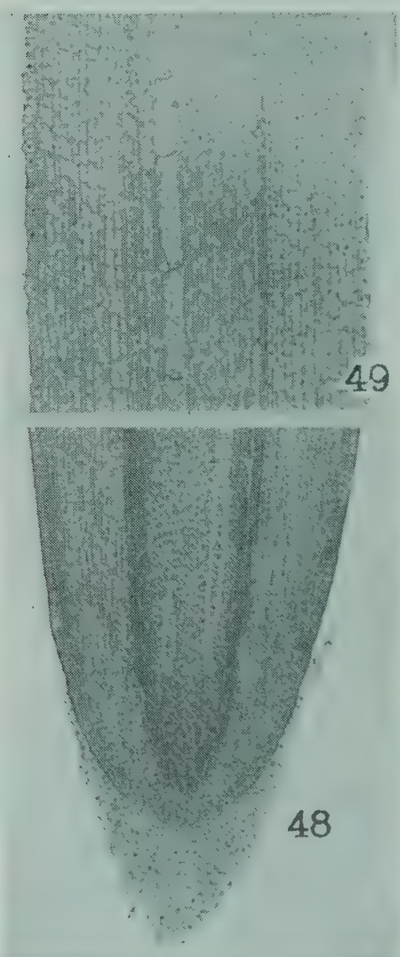
Suckers.—The suckers, or tillers, at the base of the plant (Fig. 47), are much influenced in development by nutrition, moisture, and cultivation. The various strains of corn also have distinctly different tendencies as to sucker production. In structure, these branches range all the way from normal ears to normal shoots having ears and tassels of their own.

The prophyllum.—Adaxially located at the base of every branch of the plant is a structure which, in the grasses, has received a limited application of the term "prophyllum." Although doubtless the first leaf of the lateral shoot, and usually subtending a rudimentary bud, the prophyllum has a distinctly characteristic structure. Its lamina and ligule are usually lacking, and two prominent nerves are present. The latter peculiarity is probably to be associated with the crowded quarters in which the structure develops. The palea is doubtless the floral homologue of the prophyllum.

CHAPTER IX

THE ROOT SYSTEM

The primary root, which is a downward continuation of the main axis of the embryonic plant, is a relatively unimportant structure. Very early during germination its work is supplemented by that of two or three secondary roots arising from the first node of the stem. But even these soon have their day, and during subsequent development the plant depends upon roots arising from still higher nodes. In the absence of any device for secondary thickening, none of the roots ever attain any very great diameter, and the whole root system is essentially fibrous. Even these small roots may, however, penetrate the soil to a depth of as much as 4 or 5 feet, and the root system may radiate from the base of the plant for a distance of 5 or 6 feet.



Figs. 48, 49.—Portions of a longitudinal section of a root tip.

Tissues of the root.—The tip of the root is covered with a firm, pointed cap, which bears the brunt of forcing a

way through the soil (Fig. 48). This hard usage keeps wearing away the outer part of the cap, but is continually being renewed from within.

Immediately back of the cap, in the tip of the root proper, is a region of meristematic tissue, which is the principal seat of formation of new cells as the root grows. In still older regions back of this, the plerome and periblem are differentiated, and in due time the cortex and central cylinder become well defined. When elongation has ceased, the root hairs appear.

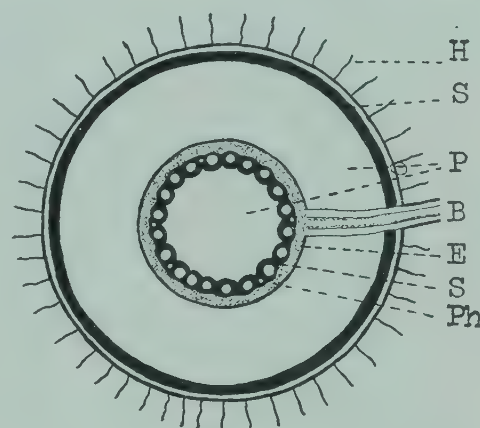
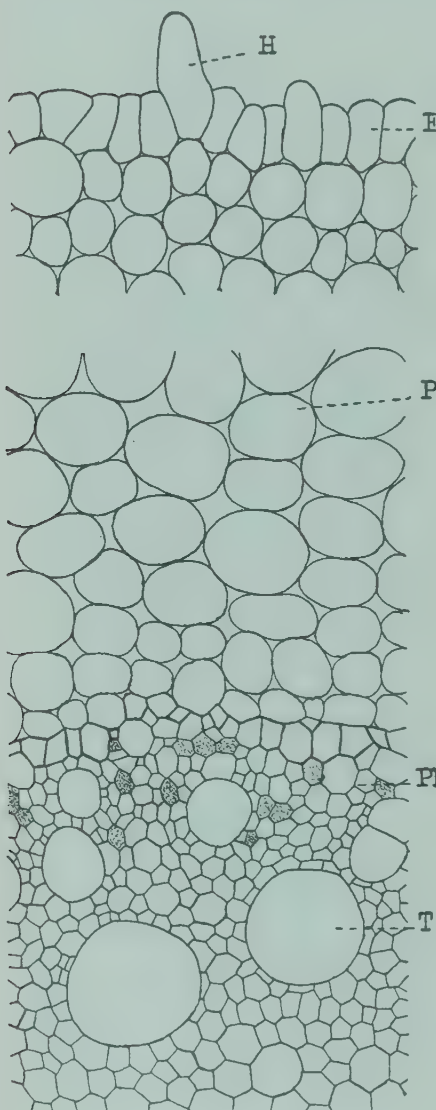


FIG. 50.—Diagram of cross-section of a young root. *H*, root hair; *S*, sclerenchyma; *P*, parenchyma; *Ph*, phloem; *B*, a branch root; *E*, endodermis.

The central cylinder contains a circle of large vessels alternating with strands of phloem (Figs. 50–52). Filling all parts of the cylinder not occupied by the vascular tissue, is a soft parenchyma. The endodermis is readily distinguished by the clear outlines and thickened radial walls of its cells.

Root hairs.—The appearance of root hairs is an incident in the maturity of the portion of the root on which they occur. A fully developed root hair (Fig. 53) is a cylindrical elongation of a single epidermal cell, rendered more or less irregular by the pressure of particles of soil around it. Its cytoplasm is mostly disposed in a wall layer, in which the nucleus is imbedded. The middle of the cell is a large vacuole, whose cell sap plays an essential rôle in the functions of the root hair.

As the root grows older, the root hairs lose their function, the epidermal cells die, and the wearing away of the outer part of the cortex begins. The whole root



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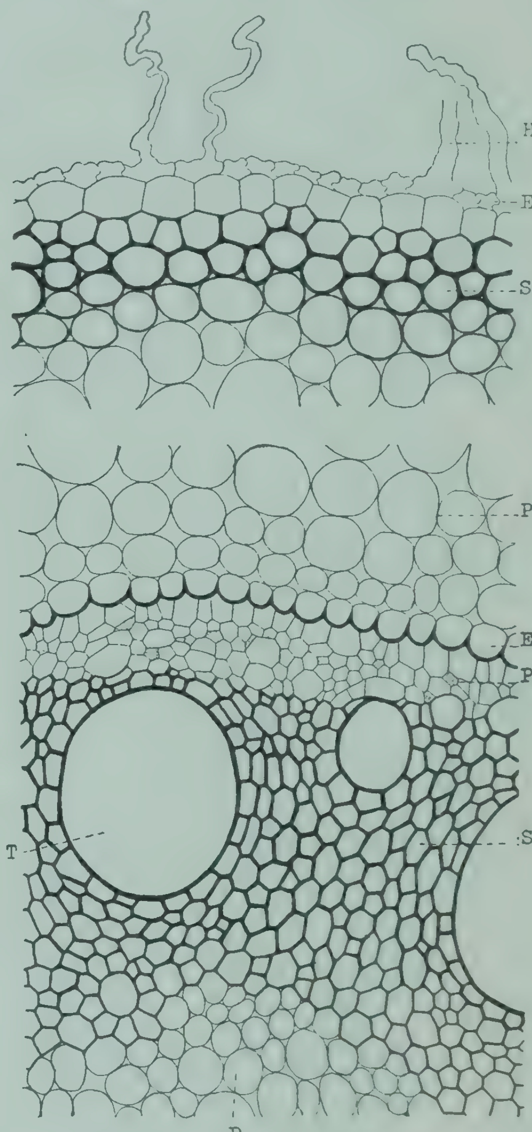

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FIGS. 51, 52.—Fig. 51, portions of cross-section of a young root. *H*, root hair; *E*, epidermis; *P*, parenchyma; *Ph*, phloem; *T*, trachea. Fig. 52, portions of cross-section of an old root. *H*, root hair; *E*, epidermis; *S*, sclerenchyma; *P*, parenchyma; *En*, endodermis; *Ph*, phloem; *T*, trachea.

increases in thickness, for a time, by the growth and multiplication of its cells, but no cambium appears, as in many plants, to bring about a continued increase in diameter.

Osmosis and root pressure.—The function of the root hair is to extract water and mineral salts from the soil and to eliminate waste products. These activities are accomplished by the process of osmosis. The entrance and exit of water and dissolved substances is regulated by the protoplasmic membrane of the root hair. Its effect is to maintain, inside the cell, a characteristic hydrostatic pressure and a concentration of solutes which is the optimum under the environmental conditions. Other epidermal cells of the root perform the same functions as the root hairs, their activity being limited only by the amount of surface exposed to the soil.

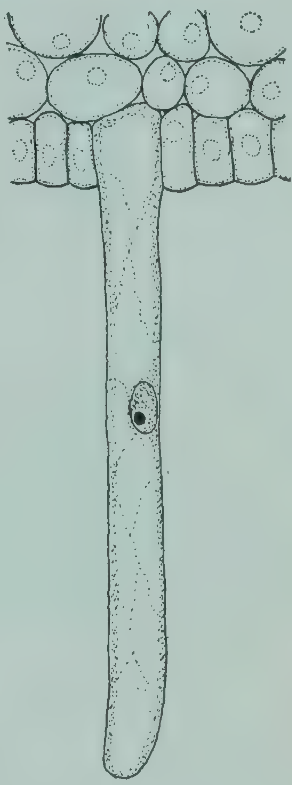


Fig. 53.—A root hair

The water taken into the root hair makes its way to adjoining cells of the cortex, where there is less turgor; and, in proceeding from cell to cell, seeking an osmotic equilibrium, it reaches the vascular tissue, which proceeds to distribute it to all parts of the plant. Some of it ultimately reaches the mesophyll of the leaves, from which it tends to escape into the air by transpiration. The rate of transpiration and guttation largely determines the amount of water taken in by the root hairs in

any given time. The ingress of minerals is regulated by the concentration present in the soil water, the concentration permitted within the cells by the various osmotic systems concerned, and the rate at which substances are taken out of solution by the metabolic activities of the plant.

Secretion and excretion.—Some of the products of metabolism make their way out of the root by way of the root hairs. Some of these may be regarded as secretions, inasmuch as they aid in the decomposition of the soil; but many of the substances eliminated by the roots have no known functions and are often toxic in effect.

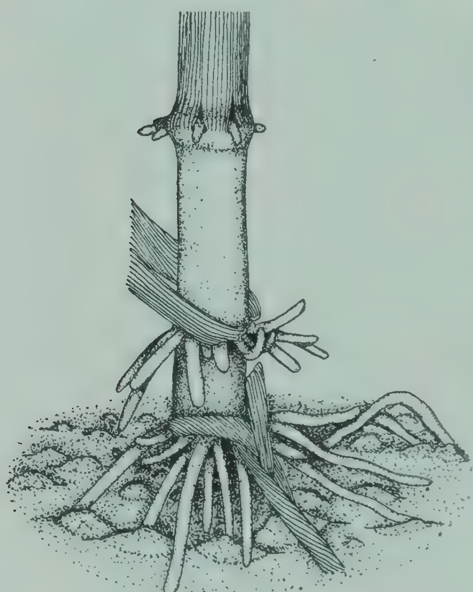


Fig. 54.—Buttress roots

Buttress roots.—Coincident with the period of rapid elongation of the stem, and usually before the appearance of the tassel, one or more nodes just above the ground may throw out whorls of large spur roots, which curve outward and downward, finally entering the soil and forming a firm support for the stem (Fig. 54). These roots are much thicker and stronger than those produced underground; their sclerenchyma is well developed, and the epidermis is silicified; and their cortical regions often develop chlorophyll or other pigmentation. Otherwise, they resemble the ordinary underground roots, even to

the large root cap. Different strains of corn and different individual plants show great variation in the production of these brace roots. In some varieties they seldom occur, and their development can usually be inhibited, to a degree, by heaping the soil about the plants during cultivation. In other varieties, however, and under optimum conditions, these roots may be developed at all the nodes of the plant up to 2 or 3 feet from the ground. They usually develop on the lower side of the stem at any node of a prostrate plant.

CHAPTER X

ECOLOGICAL RELATIONS

The most prominent factor in the ecological relations of maize is man. What man calls agriculture is, in a large measure, the making of an environment for plants. Maize agriculture is, and has been, scarcely more than man's attempt to shape the ecology of the plant; and the result is a plant so helpless that it is unable any longer to perpetuate itself without human aid. Modern maize is so far removed from the conditions that surrounded its wild ancestor that little is known of its natural environment in early times; and its ecology is reduced to a problem not of the plant but of man who acts as its agent.

Distribution.—Maize is not well adapted to chance distribution by wind or water, and to only a slight extent by animals. It was no series of chance happenings, but the intent of man, that took the plant from the limited region of its nativity, across deserts, mountains, and oceans, and into new lands, until it is known today throughout the civilized world.

Climate.—In every expression of its choice of climatic conditions, maize points to its origin in the highlands of the tropics. Bright sunshine, clear air, warm days and nights, abundant rainfall, and good drainage are all conducive to its welfare; and one of the most unfavorable conditions that can be visited upon the plant is to compel it to stand through cold, cloudy weather with its roots in a water-soaked soil.

The seed retains its vitality best if kept dry and warm from maturity until planting time, very cold weather or fluctuating humidity being very injurious. Its extreme sensitiveness, in these respects, may have been acquired in the dry seasons of its native home.

Freezing temperatures, continued for any considerable time during the growing season, constitute an absolute limit to the plant's existence. Seedlings of many varieties are able to stand a sharp frost or two, and may even recover after most of the leaves have been killed, but as much as a day's exposure to temperatures below freezing is fatal. The agricultural conquest of the colder latitudes by maize has been accomplished both by a shortening of the growing season and by the development of a hardiness to withstand temperatures near the freezing-point. But these advantages have been gained at a sacrifice of the size of the individual.

The successful growing of corn requires a season of from 90 to a 150 days without a killing frost. The varieties grown in any locality are usually adjusted to the length of the growing season, it being of advantage to use the largest variety that will mature in the season afforded. Some Canadian varieties will mature in two months from the time of planting, and some accounts, not well substantiated, report varieties that will mature in six weeks, or in extreme cases in a month. On the other hand, some of the large varieties of the tropics require a season of nine to eleven months.

It has long been observed that varieties taken into colder latitudes tend to shorten their growing season and become adapted in a few generations, and those taken

into regions having a longer summer may lengthen their growing season. The effects of selection, conscious or otherwise, is probably sufficient to explain this behavior, in view of the extreme heterozygosis shown by ordinary varieties of maize. The fact that two plantings of corn, made a month apart, may come to maturity almost simultaneously in the fall may be explained by the definitely established fact that, in many plants, a gradually shortening day tends to hasten sexual maturity—this influence being more marked in the higher latitudes than in the tropics, and in later parts of the growing season than in the earlier.

One of the most serious conditions that has to be met in the whole life-cycle of the plant is the drought that often comes about tasseling time, or a little earlier in many corn-growing countries. If the soil is moist enough to cause the seed to germinate and to get the roots well established, and if cultivation is thorough, dry weather seldom has any harmful effects before the tassels appear. But with the appearance of the tassels and the elongation of the stem, there is a great increase in transpiring surface, and the roots are often unable to supply moisture fast enough to compensate for that given off in transpiration.

The first marked indication of this lack of moisture is the rolling of the leaves. This is a normal protective measure, not in itself of any serious significance, unless continued for several days in succession; but when portions of the upper leaves turn white and begin to die, or when the lower leaves dry up, the injury has been serious. The hot winds that often sweep over level sections far inland may, in a single day, do serious

injury, even though there be no actual deficiency of moisture in the soil.

Wind and hail often damage the plant mechanically by blowing down or breaking off the stem, or by tearing the leaves. A plant that is broken off or blown prostrate is usually a total loss; if merely bent or loosened in the soil, it may straighten enough to complete its development. The extent of the damage depends largely also upon the age of the plant affected. Injury of this kind seldom comes before the tassels appear; if it occurs at the time of pollination, the chances for anything like a normal continuation of development are slight; if it follows the "roasting ear" stage, the ear may mature but there is a greater chance of decay.

Only a very severe wind can do any appreciable injury by tearing the leaves, and, in such cases, the damage done is negligible as compared with that suffered by the stems. But the severe local hailstorms of early summer often riddle the plants, sometimes even beating down the stems as well as the leaves.

Pollination.—The transfer of pollen from the stamen to the stigma is free from any complications with birds or insects, but its accomplishment is fundamentally dependent upon certain physical and climatic conditions and upon the proximity of other maize plants.

Gravity alone will accomplish pollination, but if no other influence were brought to bear, self-pollination would prevail. The slightest breeze, however, will waft the falling dust to the stigmas of other plants, and this possibly is of great moment to the species. Since the plant is monoecious, its gregarious habit and the advantages of cross-pollination are doubtless intimately associated.

The successful culmination of the series of events immediately following pollination is dependent upon a warm, humid atmosphere for a few hours at least. Otherwise, the pollen tube grows slowly, or is subject to a fatal degree of desiccation.

Weeds.—Centuries of cultivation have rendered the maize plant intolerant of the proximity of other plants which shade it or enter into competition with it for moisture. This makes it impossible to grow corn under trees and imperative that weeds be kept down, especially when the plants are young. An undergrowth of other plants later in the season is less injurious, as is shown by the successful practice of underplanting with beans, cowpeas, or pumpkins. When these are making their greatest growth, their interests are sufficiently different from those of the corn plants at that time to obviate serious competition.

Each locality has its own list of most troublesome weeds, and little may be said without going into detail. Throughout the Corn Belt, the weeds usually causing most trouble are cockleburs, morning-glories, various species of Convolvulus, twining milkweeds, ragweeds, smartweeds, and various grasses.

Birds and small animals.—Since maize is dependent upon man for its perpetuation and distribution, most animals stand in a detrimental relation. The characteristics that make the plant useful to man also subject it to the depredations of birds, mammals, and insects.

The deer and other gramnivorous mammals that raided the cornfields in earlier days have retreated before the increasing population, but woodchucks, muskrats, squirrels, and rabbits have survived the development of

the principal corn-growing regions of this country, and remain to do more or less damage to the crop in the field. Mice and rats are the cause of considerable damage to the grain in storage.

Crows, blackbirds, English sparrows, and other birds often destory the seedlings and feed upon the ears as they near maturity. Their damage, like that done by squirrels, is not so much in the amount of grain eaten as in that exposed to decay in the ears torn open.

In countries where corn has recently been taken, the birds and mammals that are destructive to maize are for the most part representatives of the local fauna which have adopted the plant after its introduction. A few cosmopolitan species, like mice, rats, and the English sparrow, have become as widespread as maize itself through their habit of following man in his migrations.

Insects.—The insects present a more serious problem than that offered by birds and mammals. The latter use maize as a supplement to a variety of other foods and may leave it unmolested if other food is plentiful; but many of the insects have followed maize in its migrations and have become so thoroughly adapted to it that they depend upon it to a much greater extent. It has probably more insect pests than any other cereal crop. The insect population is so numerous that attack upon the individual is futile, and the intimate relation between pest and host often renders mass attack hopeless.

Wireworms and white grubs[1] are destructive during the cool, wet weather of early spring because of their

[1] Wireworms are the larvae of click beetles (Elateridae). The common white grubs are the larvae of various species of the May beetle (Lachnosterna).

habit of feeding on the roots and the germinating seed. Several species of cutworm[1] also attack the plant as soon as its leaves appear above the ground. Their activity usually terminates with the coming of warm weather.

A particularly harmful group of insects in all corn-growing countries, especially those favored by mild winters, includes the various rootworms and bud worms. These are the larvae of beetles and moths. They usually enter the base of the young plant and feed on the tender internal parts. If the terminal bud is destroyed, the clump of lateral suckers that springs up gives promise of recovery, but the abnormal nature of the growth soon becomes apparent. If the bud escapes destruction, the effect of the insect's work may be seen in the perforations that the leaves carry to maturity. The stalk borer, which is the larva of a moth, makes its way into the base of the stem and upward through the pith, often emerging near the ear. Its principal effects are to stunt the plant and weaken the stem.

The billbug is a weevil common to warm countries. It pierces the stem of the young plant and burrows about in the soft tissue, finally laying its eggs and leaving the larvae to sap the strength of the plant.

In early summer, when wheat and other winter annual grasses have matured and are unfit for its food, the chinch bug[2] often transfers its attack to maize. The eggs are laid on the plant and the young bugs sap its vitality by sucking the juice from the tender growing parts.

[1] The larvae of several species of moth.

[2] *Blissus leucopteris* Say.

Both the roots and the shoot of the plant are often attacked by aphids.[1] The ants that are often so numerous on the maize plants and in the soil about the roots are probably not so injurious as are the aphids which the ants keep in domestication for their honeydew.

Many kinds of caterpillars feed on the leaves of maize, but little harm seems to be done except by occasional attacks of the "army worm."[2]

Probably the most destructive group of leaf-eating insects with which the plant has to contend is composed of the Orthoptera commonly known as grasshoppers or locusts.[3] During the long, hot summers of regions far inland these insects sometimes breed in such numbers as to be a serious meance to all kinds of vegetation; and maize often affords during the driest parts of the summer the choicest green food available. After severe attacks, there often remains of the plant only the stem, the leaf sheaths and midribs, the body of the ear, and the roots—the leaf blades, silks, husks, and even the ends of the ears having been devoured (Fig. 55).

The earworm, whose work is so often seen in roasting ears, attacks not only maize but also tomatoes and the bolls of the cotton plant.[4] Sweet corn is its favorite variety, and the prevalence of the pest in warm countries, where its other hosts are grown extensively, is largely responsible for the limited use that sweet corn has found in many sections.

[1] *Aphis maidis-radicis* Forbes and *A. maidis* Fitch.

[2] The larva of a moth, *Cirphus unipunctata* Haworth.

[3] Family Acridideae. The cicada, commonly known as the seventeen-year locust, is an entirely different insect, in no way connected with the life of the corn plant.

[4] The earworm is the larva of a moth, *Heliothis armiger* Hubn.

Grain in storage is subject to the attack of many destructive insects. Among these are the meal worm,[1] the Angoumois grain moth,[2] and the grain weevil.[3] In most instances, the larvae are more injurious than the adults. The flintiest grains are none too hard for these insects, and the softer varieties are readily penetrated. The

FIG. 55.—Field of corn damaged by grasshoppers (Indiana, 1918)

damage done by these pests is enormous, especially in localities where the winters are not cold enough to hold them in check. Specimens of corn in museums and laboratories afford an excellent breeding-place, and many fine collections have been ruined before the presence of the pests was detected.

Remedies for the attack of insects.—The remedy, if there be one, for the attacks of these insects and other animal enemies is a problem for man rather than for the

[1] Species of Tenebrio.

[2] *Sitotroga cerealella* Oliv. [3] *Calandra granaria* L. and *C. oryzae* L.

plant to solve. When man assumed a protectorate over the plant and taught it the ways of civilized life, it proceeded to lose many of the protective devices that it doubtless had; and today, in the face of the attack of its myriads of enemies, if man's aid were withdrawn, it would meet with swift extinction.

The practical ways of dealing with birds and mammals are obvious. Trapping or poisoning, and the destruction of nests, dens, and other haunts, usually give results. In the case of the insects, however, the attack must often be much less direct; it usually involves a thorough understanding of the life-history of each species of pest, and an attack upon it at the most vulnerable point in its life-cycle.

Many insects do their worst damage near the limits of their range as determined by temperature extremes. Fall and winter plowing, and the destruction of winter hiding-places, will often expose the eggs, larvae, or adults sufficiently to enable cold weather and starvation to finish their eradication. Some pests attack the plant during only a limited period in its development, and these can often be discouraged by early or late planting, so that the plant reaches the critical stage at a time unfavorable for the insect's activity.

Such insects as the earworm and the chinch bug, which have other hosts than maize, may be avoided by keeping all such alternative hosts at some distance from the cornfield. Rotation of crops is effective in dealing with many insects whose principal or only host is maize.

Weevil, or other pests of grain in storage, may be eradicated by repeated fumigations with carbon bisulphide. Well-built storage places which are kept clean

are also an aid in combating these insects. A single half-rotten ear of corn, in some out-of-the-way place where the sulphide fumes will not reach it, may offset the benefits of a very effective fumigation by maintaining a source of reinfection. The southern practice of snapping the ears from the stalk and storing them in the husk is said to be effective in preventing injury from this type of insect.

The encouragement of insectivorous birds is one of the easiest and most effective ways of meeting the difficulty in many cases. Inoculation with a disease-producing fungus[1] has proved practical in controlling the chinch bug, and it may be possible to introduce epidemics among other insect populations in a similar way.

Fungous diseases.—The fungous diseases that affect maize are less numerous than the insect pests and much less destructive. Many of the parasitic fungi are specific, or practically so, in their requirements as to host, and they have followed maize only tardily in its migrations.

The seedlings of maize are sometimes attacked near the ground by a species of Pythium, which causes them to die and fall over. This disease, commonly known as "damping-off," is favored by wet soil and poor ventilation. It is of little economic importance.

The uredo and telial phases of two rusts[2] occur on maize and its near relatives, causing red or brownish pustules on the leaf blades and sheaths. There is a marked variation in the susceptibility of individuals to this disease. Both forms usually occur late in the season, and the damage done is negligible in most

[1] *Sporotrichium globuliferum* Speg.

[2] *Puccinia Maydis* Bereng. and *P. purpurea* Cooke.

instances. The aecidial phase of one of these parasites is thought to occur on a species of Oxalis.

Several distinct parasitic forms are responsible for a frequent condition in which the maize plant wilts, and its leaves turn white and begin to die, at the ends, without any evidence of insufficient moisture in the soil. One of these is due to bacteria which multiply in the vascular tissue of the stem and cut off the water supply by clogging the vessels. A root rot due to a fungus often deranges the vascular functions in a similar way, the effect being in the form of a blight. An apparently different disease, or group of diseases, of widespread occurrence over the United States, causes the affected plant to assume much the same appearance as these, but it has not thus far been definitely connected with any parasitic organism. Its prevalence on soils having a high content of certain metallic mineral substances leads to the belief that it may prove ultimately to be due to the toxic effect of chemicals.

Following the attacks of the earworm, birds, or squirrels, as a result of which fungous spores and moisture gain access inside the husk, the whole ear or a part of it may decay. This damage, however, may more properly be charged to the agency that opened the husk than to the fungus immediately responsible.

Similar to this in appearance is the effect of the specific ear-rot fungus,[1] which enters the roots of the young plant from the soil, or from an infected endosperm, and makes its way up the stem, attacking and completely destroying the ear as it nears maturity. Certain species of Fusarium are also known to be responsible for similar ear rots.

[1] *Diplodia Zeae* (Schw.) Lév.

These diseases are widespread, and their economic importance is rapidly coming to be recognized. Not only do they destroy good ears of corn, but certain pathological conditions in animals and in man have very reasonably been attributed to food containing such decayed corn. Infection is carried from generation to generation on the seed or in the stalks and decayed ears left in the field at husking time.

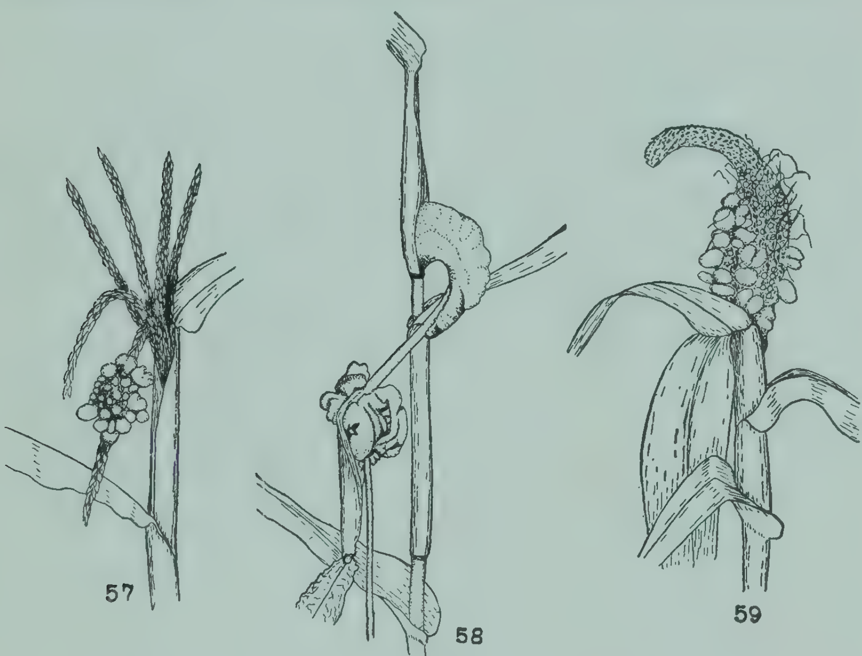
FIG. 56.—Smut on staminate inflorescence

The best-known, and probably the most destructive, disease of maize is smut or "brand."[1] This disease is common in every corn-growing country of the world, although it would be one of the easiest of diseases to leave behind whenever corn was taken into a new country, since the rather uncommon teosinté is the only other host, and the causal organism is not carried on or in the seed.

Infection occurs at any time during the growing period of the host, but the fungus can gain entrance only through wounds, or to succulent, growing tissue.

[1] *Ustilago Maydis* (DC.) Corda.

The floral parts, the nodes, and injured parts are especially open to attack (Figs. 56–59). The effect is a white or greenish hypertrophied malformation consisting of the tissue of the host permeated with the mycelium of the parasite. As the fungus matures, these growths turn black, due to the segmentation of the mycelium into a mass of black, dustlike spores. These remain in the



Figs. 57–59.—Smut on various parts of the plant

field during the winter and germinate in the spring, immediately forming spores of another kind, which proceed to infect a new generation of the host.

This fungus destroys the ear in many instances, and is very objectionable when introduced into foods made from the plant for man or for live stock. In ensilage, its effects are obvious. Cattle that have eaten large quantities of ears partly destroyed by smut sometimes suffer from poisoning similar to that due to the

ergot of rye.[1] The mature spores are uninjured in the digestive process, and their presence in the manure is most favorable for the reinfection of the host.

With the exception of smut and the ear rots, the fungous diseases of maize cause relatively little damage, and preventive measures have attracted little attention.

The fact that most of these disease-producing organisms spend the winter in the field, where the corn was grown, renders very effective such measures as the rotation of crops and the destruction of all diseased plants as soon as they are detected. The planting of uninfected seed is important in dealing with the ear rots. The great variation shown in resistance to disease by different varieties makes the selection of hardy strains an undertaking of promise.

Corn smut cannot be controlled by any of the treatments of the seed, which are used so successfully in the case of some of the other cereals affected with smut, because the spore that is to infect the coming generation is not on or in the seed, but remains in the field during the winter. The general sterility of the plants affected by smut, since the inflorescence is very often destroyed, tends naturally to eliminate by selection the susceptibility to the disease.

[1] The common practice of leaving in the field at husking time the ears that have been wholly or partly destroyed by smut, and then pasturing the field with cattle, or other stock, is especially likely to lead to this trouble, since the animals spend the first few days in gleaning the ears that have been left, and eat large amounts of the fungus.

CHAPTER XI

SEED AND PLANTING

Many different varieties of maize are grown in widely diverse lands, and the planting, cultivation, and harvesting of the crop constitute a comprehensive set of processes. But the general principles involved are the same, whether followed by the scientific farmer of the Corn Belt, or in some mountain valley of Peru, where the half-breed still manages his farm as did his forefathers in the days of the supremacy of the Incas.

The individual maize plant requires much more space than does the individual of any of its cereal relatives, and it responds well to any measures taken to conserve moisture and eliminate the competition offered by weeds. Grouping the plants in hills facilitates cultivation and aids in pollination. The Indian usually arranged the hills in rows, because this was the easiest way to space them equally, and gave the field a better appearance; and the white man adopted this method of planting as an adaptation to linear cultivation. The methods of manipulation of the corn crop in the Corn Belt—the main body of the Ohio-Mississippi-Missouri Valley—are the standard of the world. More intensive methods may be employed in other localities, and higher yields per unit of area may be produced elsewhere, but the practice of this section is the type of the highest scientific achievement in the growing of corn on a large scale.

The seed bed.—After the removal of any coarse débris left from the crop of the previous year, the

ground is broken. When this work is well done, a layer of soil 4 to 8 inches in depth is completely inverted, and little or no vegetable matter is left uncovered.

The next step is to pulverize the soil and to work it down to a compact seed bed. The method varies with the kind and condition of the soil and with the available equipment. The implement in most common use is a spike-tooth harrow. A disk harrow may be used to

FIG. 60.—A good field of corn (Indiana, 1921)

pulverize deeply and produce a better contact with the subsoil when sod or coarse material has been turned under. Various types of rollers may be used when there are many hard clods to be broken, and a drag is useful in pulverizing an inch or two at the surface.

In the usual rush to get the seed into the ground in proper season, the value of a good seed bed is often underestimated. Thorough preparation at this time may be made to take the place of one or more cultivations

after the corn has come up; and the work can be done much more thoroughly and economically at this time than later when the plants must be guarded from injury. Moreover, a well-prepared seed bed will better retain moisture at a time when the supply is often deficient, and this is conducive to uniform germination and a good stand.

Selection and care of the seed.—The practice of selecting the seed corn in the field, an innovation of only the last few years in many localities, is rapidly becoming popular. Besides affording a better opportunity for judging hereditary qualities of the whole plant, this method makes it possible to take much better care of the seed.

The ears selected in the field are dried as quickly as possible by exposure to the air while loosely arranged on racks or shelves. Artificial heat is often employed advantageously. After thorough drying, the seed should be protected from moisture and from extreme cold until planting time. The popular idea that the retention of vitality is dependent upon a perceptible amount of moisture in the place of storage is fallacious. If high temperatures are avoided, no place is too dry for the storage of seed corn. Fluctuating humidity is especially to be avoided.

Viability and testing.—Since viability is greatly influenced by the conditions under which the seed is matured, dried, and stored, the testing of a few grains from each ear has been found to be very profitable.

Many types of seed tester are in common use, the essential requirement being that it provide small, numbered compartments affording conditions proper for germination. The ears to be tested are given numbers

corresponding to those of the compartments of the tester. Five grains taken from different parts of the ear constitute a satisfactory test portion. An ear that fails to show perfect germination of the seeds tested is usually rejected.

The enthusiastic beginner often makes the mistake of surrounding the test seeds with conditions better than those under which germination normally takes place; and this may give positive results with seeds whose vitality is too low for field conditions.

The importance of seed testing is rapidly coming to be recognized. For the effort spent, the farmer receives probably a greater return from this than from any other labor expended on the crop.

The well-established idea that seed corn that is more than a year old will not give satisfactory results is without foundation. Corn that is well cared for retains its vitality for at least two years, and in many cases much longer.[1] It is often better to use two-year-old seed from a crop that is well matured than one-year-old seed that has been damaged by early frost or by wet weather at harvest time. Few tests have been made to determine with accuracy the extreme limit of viability, but ten-year-old seed that has been well cared for has been known to give a fair percentage of germination. The soft starchy and sweet varieties deteriorate more rapidly than the flinty varieties.

Grading.—Since the principle involved in all modern corn-planting machinery presupposes a uniformity in the size and shape of the grains, some system of grading the seed is necessary for best results. The careful selection of the ears and the removal of the imperfectly

[1] See pp. 33–34.

formed grains from the base and the tip of the ear are usually sufficient, but this procedure is sometimes supplemented or partly replaced by the use of a series of grading screens, which remove all grains not in conformity with the adopted type.

Hand planting.—Until fifty years ago the hand method of planting was in general use, but this work is now done better and far more economically by machinery. When the hand method was employed, the field was laid off in furrows, and into these the grains were dropped by hand, singly or two or more in a hill. A plow or hoe was used for covering.

If it were desired that the hills be checkrowed, the field was first marked in one direction and then furrowed off at right angles to these marks. Three or four grains were dropped in the furrow at each intersection with a mark. When carefully carried out, this method is still unequaled for accuracy. But it is slow and expensive; the child labor formerly employed to drop the seed was a source of much irregularity; and the stand was often uneven because of a lack of uniformity in the depth of covering.

Corn planters.—The earliest corn-planting machines to be used on an extensive scale were one-horse drills, which, at a single process, opened a furrow, dropped the seed, and covered it, planting one row at a time. Better work could be done, however, if the furrow were first opened with a plow. Within their limitations, these usually did good work, and they may still be seen in use in many places.

A modern corn planter is a highly developed, yet simple, piece of apparatus. At a single process it plants

two rows, drilled or in hills, adding fertilizer if desired, and marks a line to be followed in planting the next two rows.

The essentially important part of the machine—and the part that has undergone most evolution—is the device for releasing the grains at regular intervals. This consists of a rotating circular plate, forming the bottom of the seed box, and having around its circumference a number of holes, each of which holds a single grain. At the proper time in the course of a revolution of the plate, each hole releases its grain into a tube leading to the ground. Interchangeable plates afford different sizes of holes for different varieties of corn, and the interval at which the grains are dropped may be modified by a set of gears providing for different speeds of the revolving plate.

The furrow for the seed is opened by a disk or by a share made of two flat pieces of steel united in front but separated a few inches at the rear. The seeds are dropped into the furrow, and the soil falls into the furrow and covers them as the implement passes on. The wheel of the planter follows and presses the soil firmly. If the soil is heavy, or if, for other reasons, this pressure is not desired, various adjustments are provided for avoiding it.

When the corn is to be planted in hills, there is provided near the ground, in the tube leading from the seed box, a pocket which holds the grains as they are dropped until the place for a hill has been reached, when all the accumulated grains are released at once.

Checkrowing.—This release is usually accomplished by a wire running across the field parallel to the rows and

passing through a part of the mechanism of the planter. At proper intervals, this wire has knots, which operate the dropping device; and, as the wire moves across the field in the progress of planting, each knot marks, by its course, a row at right angles to the rows marked by the progress of the planter.

The checkrow system of planting offers many advantages over other systems, and it is generally employed throughout the Corn Belt. It groups the plants in a manner conducive to effective pollination, makes possible cultivation in both directions, and greatly facilitates some methods of harvesting.

Intervals of planting.—In the Corn Belt, the standard distance between the rows is $3\frac{1}{2}$ feet. When the crop is drilled, the individual grains are dropped at intervals of 12 to 18 inches. Two to four plants to the hill is the rule when the checkrow system is used. Moisture, fertility of the soil, and special requirements of different varieties determine the distance between the rows or between plants in a row.

Listing.—A method of planting extensively employed in the arid regions of the Southwest, and also in the South, where the technique is borrowed from the cotton industry, is known as "listing." The only preparation of the soil is the opening of a deep furrow by means of a special type of plow. The corn is planted in the bottom of this furrow, which is gradually filled by cultivation as the plants grow. Listing has the advantage of getting the crop started early in the spring, and the deep planting is also advantageous in dry climates.

CHAPTER XII

TILLAGE

Probably no phase of the complicated relationship between man and maize is characterized by more superstition and pretty theorizing than is the cultivation of the growing plant. The uncertainty on this point, and the error of many methods of cultivation, may be traced to a general ignorance of the fundamental principles of plant physiology.

Reduced to fundamentals, the aims of cultivation are: (1) to conserve moisture in the soil and increase its capacity for moisture; (2) to kill weeds; (3) to admit air to the soil; (4) to aid the underground parts of the plant in penetrating the soil; and (5) to bank the soil around the plants for support. It is not to be inferred that the tiller of the soil is always conscious of these aims, or that he need be for successful results. He has found, rather, a routine of processes that give good results, and practicability is his guide. Statistics show that the commonest aim of which the farmer is conscious is the destruction of weeds;[1] but a careful analysis will doubtless show that, in many instances, the benefits accruing incident to this aim are of much greater value than the achievement of the aim itself.

Conservation of moisture.—Under present conditions, the conservation of moisture is the critical problem of tillage, and the problem about which least is definitely understood by the practical man. A dust mulch does not induce capillarity or *draw* moisture from below in

[1] See Cates (18), pp. 1–2.

any other way. It is really effective in *preventing* capillarity in the surface layer of soil.

In moist but well-drained soil, each minute particle is wet with a film of water, which is held by capillarity. Deep down in the soil there is always a level below which all the spaces between the particles are filled with water. On the other hand, the topmost layer of soil, in contact with the air, is continually losing its moisture by evaporation. Capillarity not only causes a film of moisture to cling to each particle of soil, but it also enables a dry particle to rob a wet one of a part of its moisture. Thus, each particle replenishes its supply of moisture from particles below, and the loss by evaporation is continually being replaced by a supply drawn from the deep, saturated layer.

In dry weather, this region of saturation sinks lower and lower, and the passage of water upward becomes more and more slow. Any surface layer through which the water cannot pass by capillarity will diminish evaporation and leave more water for plant life. Dead leaves, straw, or other vegetable mulch may be used for this purpose, but, when a whole field is to be treated, the only practical protective layer is one of dust, produced by pulverizing the surface layer of soil. The pulverizing process leaves the particles of soil so far apart that moisture does not readily pass from one to another by capillarity. Rain, pressure, or even the mere settling of the soil after a time, will re-establish these capillary tracks. Consequently, the mulch must be renewed after each rain, or oftener. A light rain, by saturating the mulch without wetting the soil any deeper, may thus do more harm than good.

Other aims.—Although the conservation of moisture is probably the most important problem of tillage, and other aims are usually accomplished incident to this, yet the progress made by weeds is not a bad index to use as a guide for cultivation. The very conditions that make weeds noticeable also demand cultivation for other purposes. A rain, or compression of the soil by mechanical means, causing seeds to germinate, and bringing on a crop of weeds, also necessitates the renewal of the dust mulch. Cultivation definitely directed toward the eradication of weeds after a long period of wet weather is also much needed for aeration of the soil.

Implements.—The most primitive horse-drawn cultivator was the single-shovel plow. Thorough cultivation with it required ordinarily five trips to the row. This type of plow is still largely used in many parts of the South, but, in the more progressive sections of the Corn Belt, it was early replaced by the double-shovel, which required the same labor from the man, and scarcely more for the horse, and did the work of cultivating a row at two trips. The modern two-horse cultivator is two of these double-shovel plows fastened to a wheeled frame, one handle of each having been eliminated. Many types of this implement are in common use, but they differ only in details. Some have a tongue, and some do not; some provide a seat, and even a sunshade, for the driver; some have only four shovels, but others have six or eight; almost all have interchangeable shovels of different sizes and shapes; and some have disks instead of shovels. The latest step in the evolution of this implement is the two-row cultivator now in use

on many of the larger farms. One man with three horses, or a tractor, can do with this cultivator ten times as much work in a day as he could do with the old single-shovel plow.

Various kinds of harrows and drags are also in common use, and special plows for killing special weeds or loosening special kinds of soil are also used in many places.

Processes.—The corn plant's first struggle with its environment is in getting the young shoot out of the ground. The firm plumule sheath usually makes its way through the soil very readily; but if the soil is heavy, or if a hard rain has followed planting, the young plant must be given help, if its success is to be assured. Some type of light harrow is often used to break the crust on the soil at this time.

As soon as all the plants are up and large enough to be seen distinctly, the first thorough cultivation is given. Small shovels are ordinarily used on the cultivator, and the soil is loosened deep and close to the plants. Subsequent cultivations are shallower. The idea prevalent in many sections, that cultivation should be deep enough to stir the roots, is entirely erroneous. Anything that tends to break the roots or disturb their adjustment to the soil is to be regarded as a decided menace.

The number of cultivations varies with conditions, from one to six being given in different places. If the hills are checkrowed, one or more of the plowings are done at right angles to the direction of planting. This cross-cultivation is one of the most effective that the crop receives, and it is, in itself, ample justification for the checkrow system of planting.

During the progress of cultivation the soil may be kept level, but there is usually a tendency to throw it toward the plants, forming a ridge. This practice is intended primarily to give support to the base of the plant, but recourse is often had to it as a more efficient method of killing weeds. Excessive ridging exposes increased surface to evaporation and is to be condemned when the conservation of moisture is a serious problem.

The use of the two-horse cultivator is terminated by the growth of the plants to a height at which they will not pass under the arch of the implement. In the days of the one-horse plow, cultivation was often continued far beyond this, even beyond the time of flowering; but the wisdom of this course is doubtful, for, as the plants begin to shade the ground, and evaporation is thus decreased, a thick network of fine roots is developed near the surface, and the damage done to these usually more than offsets the benefits of this late cultivation. Good work can be done at this time, however, by means of a light drag just wide enough to pass between the rows, thus pulverizing the soil at the surface without disturbing the roots.

CHAPTER XIII

HARVESTING

Which of the many and varied uses of the corn plant is to be given chief prominence determines the method of harvesting. In the matured grain is stored most of the material that is useful to man, and the process of harvesting is usually centered about the welfare of the ear.

Pasturing.—When corn is plentiful and cheap, and labor is expensive and hard to secure, recourse is often had to the simple expedient of turning live stock into the field to do the harvesting. The limitation of this method to practically the one kind of stock, which cannot be injured by overfeeding, and assimilates in proportion to what it eats, has given this procedure the somewhat inelegant name of "hogging." Aside from the saving of labor, this method has also the advantage of returning to the soil as manure all that the best agricultural economics can demand. But the fodder is a total loss, and much of the grain is wasted. Except under unusual conditions, as when the crop is poor or has been injured by frost or other unusual weather conditions, or when the labor situation is unusually critical, it is more profitable to take care of the crop in some other way.

Husking in the field.—Throughout the Mississippi Valley, the bulk of the crop is left in the field until thoroughly matured and dry enough to be stored immediately after harvest. In the absence of any machine that can make even a pretense at this work, the husking of corn by hand has become very much of an art. The

only appliances used are a husking peg and sometimes a pair of gloves or some other protection for the hands. As the ears are husked they are thrown into a wagon which is kept alongside the work. From the field the grain is taken directly to the crib.

The value of the fodder is materially reduced by weathering during the time required for full maturity of the grain, frost followed by rain having an especially deteriorating effect. But after the removal of the grain, there is much to be gained by pasturing the field with cattle, sheep, or horses to harvest the fodder and glean grain that has been left in husking. The stalks left on the ground are broken down or cut up with a stalk cutter before the ground is plowed for the next crop.

Cutting.—A varied group of processes, giving in general the maximum opportunity for the use of labor-saving machinery, have grown out of the custom of cutting and shocking the plants early in the fall. The proper time for cutting is indicated by the loosening of the dry husks, the plants being sufficiently dry at this time to be massed in shocks without danger of molding.

Until recent years, practically all corn cutting was done by hand; and, although efficient machinery for doing the work has been available for many years, hand cutting still prevails in many localities. The implement used is a straight, heavy knife 18 to 24 inches long.[1] A support for the beginning of the shock is made by weaving together the tops of three or four hills in two adjacent rows. Five or six rows on each

[1] In certain localities in Indiana, there is in use a form of knife which is fastened to the shoe, and for which some remarkable results are claimed.

side of this "gallows" are cut and set around it, ten or twelve rows of corn usually making a shock row. The shocks are spaced in the row at about the same interval as the distance between the shock rows (Fig. 61). The finished shocks are tied with twine, cornstalks, or some other device.

A simple modification of hand cutting makes it possible to use advantageously a horse-drawn implement.

Fig. 61.—Corn in the shock (Indiana, 1921)

This is a sled or low-wheeled wagon, narrow enough to pass between two rows, and bearing on each side a horizontal wing armed with a knife to cut the stalks. The two operators sit back to back in the middle of the machine, each giving his attention to a single row. The stalks are grasped near the ear just as the knife reaches them, and held firmly until cut off. When a shock is reached, the machine is stopped, and the armfuls of plants that have accumulated since the last shock was passed are set up. The shocks are tied as when cut by hand.

Binding.—The self-binding corn harvester has been improved to thorough dependability, and is rapidly winning the place that it deserves in the manipulation of the crop. Taking a row at a time, this machine cuts the plants and binds them in bundles of convenient size. These are set up in shocks in the same manner as the sheaves of the smaller grains.

The corn shredder.—The husking of the corn that has been cut is often done by hand, the fodder being fed without further treatment. But much of the advantage to be gained from cutting the crop is lost if use is not made of modern husking and shredding machinery.

The type of corn shredder in common use today is a very efficient piece of machinery. The plants, which have become thoroughly dry in the shock, are fed into the machine between two rollers, which crush the stalks and snap off the ears. The latter fall into another set of rollers armed with small, hooked teeth for removing the husks. On leaving the husking rolls, the ears are picked up by an elevator and carried to a wagon or other receptacle. The husks and other fodder pass into a shredding device from which the macerated material makes its way, through a pneumatic elevator, to the place of storage. The shredded fodder is usually fed in this form, but it may be baled if it is to be transported long distances or if storage space is limited.

Aside from the labor-saving phase, the shredding process has other advantages. By loosening the leaf sheaths and husks, it makes available for food the maximum amount of fodder. The residue left by stock also makes good bedding and is an excellent absorbent for the liquid manure.

Fodder-pulling.—In some parts of the United States, mostly in the South, economic conditions make profitable a practice known as "fodder-pulling." When the leaves of the plant are fully mature and beginning to dry, but before there has been any deterioration from weathering, they are pulled off by hand and hung over the ears or pushed between the stalks of a hill to dry. When dry, the fodder is stacked, or stored otherwise, until needed (Fig. 62). Thus, the fodder is removed at the time of its maximum value and dried without weathering, and the ear is allowed to remain on the stalk until fully matured.

FIG. 62.—Stacks of "pulled" fodder (Georgia, 1920).

Topping.—A modification of this method takes advantage of the fact that, by the time the leaves are mature, the portion of the stem above the ear is no longer essential to the perfect maturity of the grain. Accordingly, the plant is "topped" just above the ear. These tops, with the leaves from the lower part of the stem, are shocked and left in the field to dry.

When topping and fodder-pulling have been practiced, or when it is desirable to save time in harvesting, the

ears may be snapped from the stalks and stored in the husks. The grain may be fed to many kinds of stock in this condition, but it is usually profitable to husk the ears later and feed them and the husks separately.

These hand methods of harvesting, based upon fodder-pulling, are employed chiefly on small farms where the crop is grown for home use rather than for commercial purposes. It is characteristic of the corn industry in sections where corn is not king.

Ensilage.—Corn is more extensively used today than any other plant for making ensilage. For this purpose, it is usually cut by hand several days before mature enough to be cut and shocked. It is immediately run through an ensilage cutter, which cuts stems, leaves, and ears into bits, and elevates the whole mass into a silo. Here it is packed so tightly that most of the air is driven out and only the incipient stages of fermentation can occur. Practically the whole plant is succulent and nourishing at this time. Ensilage is used chiefly for the winter feeding of dairy cattle.

CHAPTER XIV

THE INFLORESCENCE

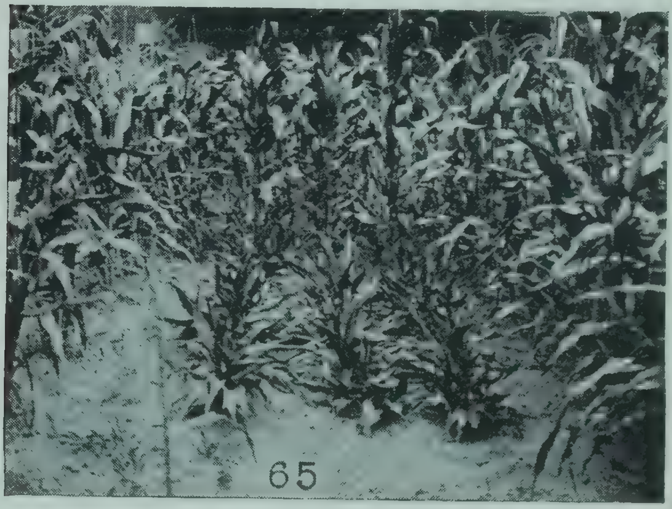
In its commonest and most highly specialized form, maize is a monoecious plant. The staminate flowers are borne in the *tassel*, terminating the main axis of the stem, and the pistillate flowers in the *shoot*, a specialized branch of the stem, which bears a conspicuous tuft of red or greenish-yellow *silks* at flowering time. But, even from the most remote times that have given us any account of the plant, striking departures from what is considered the normal condition have been known to occur frequently.[1] These variations complicate description, but are of material aid in the interpretation of structure and development.

FIG. 63.—A type of degeneracy produced by inbreeding.

As in all grasses, the flowers occur in definite spikelets. Although the staminate and pistillate spikelets are

[1] In the days of the early Spanish explorations in Mexico, the Indians had elaborate religious ceremonies centered about branched ears of maize and ears borne in the tassel. See Fraser (64), p. 173. The Indians of Northeastern North America also attached peculiar significance to crooked, or otherwise deformed, ears. See Longfellow's "Hiawatha."

very different in appearance at flowering time, they are much alike in essential details, and it is evident that their difference in appearance is due to the abortion of some



FIGS. 64, 65.—A dwarf (brachyic) type isolated by inbreeding. This variety has a very primitive form of pistillate inflorescence.

parts and the unequal development of others. In the formative stages of development, every spikelet in either inflorescence has the primordia of two perfect flowers.

The staminate inflorescence.—The staminate panicle varies in form with the variety of maize and the condi-

tions of development. Its central axis is the continuation of the main vegetative stem of the plant. The

FIGS. 66–71.—Figs. 66, 68, widely different types of tassel found in ordinary varieties of field corn. Figs. 67, 70, reduced types resulting from inbreeding. Fig. 69, tassel of a Peruvian variety grown in Indiana. Fig. 71, tassel with a short, thick central spike; this character is often associated with the type of ear shown in Fig. 132.

spikelets are borne on the terminal portion of this axis and on a number of branches below this terminal portion. These branches are spirally arranged around the axis, the two-ranked plan of vegetative structure being abandoned.

The tassel of a depauperate plant may be reduced to the central spike (Fig. 70). On the other hand, in some large, vigorous varieties grown in a good environment, the tassel may be 2 feet or more in length and may bear thousands of spikelets. Secondary branches may or may not be present, and their presence or absence seems to be independent of the size of the inflorescence.

Fig. 72.—Fruiting tassel of pod corn

In some varieties, the axes of the spikes of the tassel are thick and rigid, giving the whole structure a stiff, erect appearance; in others these axes are thin and flexible, and a decidedly drooping appearance is the result. The peduncle may be long enough to hold the inflorescence well above the leaves, or it may be so short that the tassel is partly included in the sheath of the topmost leaf. Certain wide variations from this range of form will be described elsewhere.

In all parts of the staminate inflorescence, the spikelets are usually arranged in pairs—one sessile and the other pediceled; but groups of three or four may occasionally be found (Figs. 73–75). On the lateral branches, the pediceled spikelets are symmetrically arranged in two rows, and abaxial to each of these is the correspond-

ing sessile one. This gives the whole spike a definite dorsiventral aspect, which is lacking in the central spike, where the pairs of spikelets are arranged in several longitudinal rows distributed around the axis. In other words, the lateral branches are distichous with reference to the arrangement of their pairs of spikelets, and the central axis is polystichous with respect to the arrangement of the branches at its base and the spikelets on its upper portion. In its most reduced form, however, when the staminate inflorescence consists of but a single spike, distichism and dorsiventrality may be evident in the central spike as in the lateral branches of the larger inflorescences.

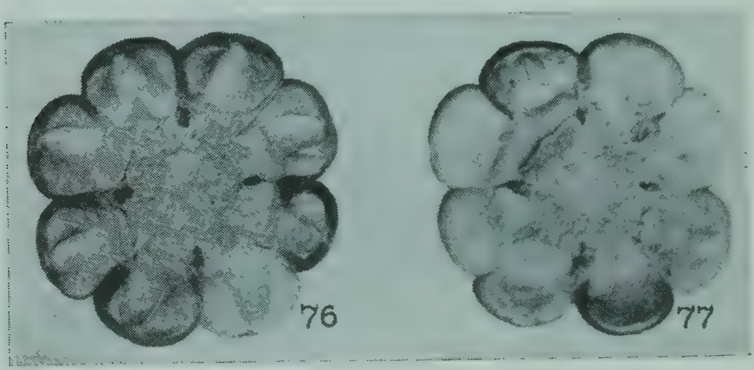
FIGS. 73–75.—Staminate spikelets.

The pistillate inflorescence.—The forerunner of the "ear" of corn is a unique structure among the grasses. It is a spike, on whose thickened axis the paired spikelets are borne in several longitudinal rows, as are the staminate spikelets on the central axis of the tassel. Each row of pairs of spikelets contributes to the make-up of the ear two rows of grains, this explaining the regular occurrence of an *even* number of rows of grains on the ear (Figs. 76, 77). Both spikelets in the pair are usually sessile, and the two are indistinguishable except in early stages of development.

Sexual anomalies.—The unstable sexual condition of the flowers of maize, and the possibility of the develop-

ment of the wrong set of floral essentials in an inflorescence, lead to the frequent occurrence of anomalies. Some of these, which affect only the spikelets or the flowers, will be discussed in the next chapter. Others, however, affect the entire inflorescence.

It is believed by some that maize represents a step in the expression of an orthogenetic tendency toward dioecism. The peculiar structure of the plant indicates that the culmination of this process is improbable as



FIGS. 76, 77.—End views of the basal and tip portions of a broken ear, showing pairing of rows of grains.

long as maize remains a cultivated plant, for this would materially decrease its usefulness; but the problem is an interesting one botanically.

Sterile plants, having normal tassels but no pistillate branches, frequently occur in cornfields and often constitute a factor of perceptible importance in decreasing the yield. This tendency toward dioecism is thought to be inherited, and the elimination of such plants before the maturity of their pollen is of importance.

The evolution of purely pistillate plants seems much less probable, for it would require the elimination or

complete metamorphosis of the tassel. Certain tendencies in the latter direction by plants grown in the greenhouse in the winter, and by the pistillate tassels of pod corn (Fig. 72), are probably not to be regarded as very significant. The nearest approach to dioecism in the future evolution of the plant is in the development of dimorphism, one form being monoecious and the other staminate.

The central spike of the tassel, and less often the branches of this structure, may, for a part of their length, assume the form of the pistillate spike and produce fruits, the remainder of the inflorescence being of the normal staminate form.

A common anomaly of the ear occurs through the replacement of a part of the pistillate spikelets with staminate units. The commonest form of this is the ear with a staminate tip (Fig. 78), whose axis is slender like that of the central spike of the tassel. Less commonly the staminate portion is at some distance from the tip, between two pistillate portions (Fig. 80). Small groups of staminate spikelets may also occur anywhere on the ear.

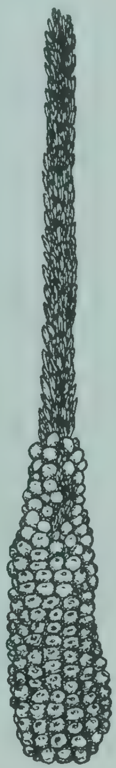


FIG. 78.—Ear with staminate tip.

At the point where the androgynous spike changes from one type of spikelet to the other are often found transitional forms, where the two spikelets of a pair, or the two flowers of a spikelet are not alike. In such instances, there is a marked tendency for the lower elements of the pair to be pistillate and the upper staminate.

Functionally perfect flowers also occur, but the definite protogyny of the inflorescence, and the inclosing sheath of husks on the ear, where hermaphrodite flowers are most common, usually render the pollen of no avail.

FIGS. 79–81.—Fig. 79, fasciated ear. Fig. 80, ear with staminate portion at some distance from tip. Fig. 81, branched ear

Branched ears.—Several distinct types of branching occur anomalously in the ear, and no general explanation of these is possible (Figs. 79 and 81). Some are doubtless due to environmental influences, while others are deep seated in origin and have not yet been explained.

A variety has been isolated in which the pistillate inflorescence is a panicle much like that of kafir corn or other sorghums. The tassel of this variety is also more

diffuse than that of the normal plant (Figs. 84 and 86–91). This is a hereditary anomaly recessive in behavior.[1]

The base of the otherwise normal ear is sometimes surrounded with a whorl of branches, each bearing four or more rows of grains (Fig. 82). These branches are probably reversional suggestions of those lost in the evolution of the shoot when the inflorescence was drawn, phylogenetically speaking, into the leaf sheaths by the contraction of the axis of the pistillate shoot. The branches of the pistillate shoot, which sometimes occur as small ears in the axils of the husks, are in no way the equivalent of these branches at the base of the ear.[2]

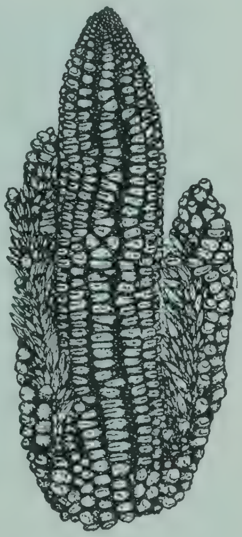


FIG. 82.—Ear with branches at base.

Fasciation sometimes occurs at the tip of the ear, the structure at this point being flattened and slightly divided into many growing-points. This anomaly seems to be inherited in some varieties (Fig. 79).

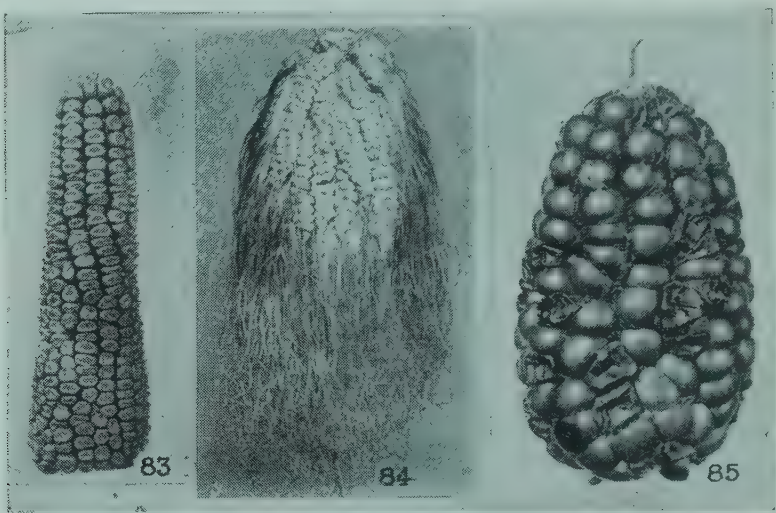
The bifurcate or three-parted ears often encountered are, as a rule, fluctuating anomalies of development, having no evolutionary significance (Fig. 81). They may be produced artificially by injuries to the plant during development. One or more hereditary cases of this anomaly have been reported, but there is nothing to indicate that they represent anything more than sporadic mutations.

The inflorescence of suckers.—The variable terminal inflorescences of suckers range all the way from the

[1] Gernert (68).

[2] See p. 58 and Figs. 44 and 45.

normal ear to the normal tassel. Some suckers remain sterile throughout the life of the plant, the terminal inflorescence being rudimentary or entirely lacking. Others are like normal pistillate branches except that they grow low on the plant and take root in the soil. Larger and more vigorous shoots have this pistillate portion surrounded by a number of staminate or androgynous



FIGS. 83–85.—Fig. 83, a type of conical ear, having eighteen rows of grains at the base and ten at the tip. Fig. 84, ear of branch corn. Fig. 85, an androgynous ear.

branches, and all gradations occur between this and the normal staminate panicle of large, well-developed suckers having ears of their own (Figs. 92–94).

The conditions determining the form of the inflorescence of the suckers have never been investigated in detail. Heredity plays an important part, but light, moisture, and nourishment are probably to be considered. The extent of the root system of the sucker, and the consequent degree of independence of the latter, are influential. These factors may also be complicated by

the relation between the physiological activities of the main shoot and the time at which the primordia of the inflorescences of the suckers are differentiated.

FIGS. 86–91.—Tassel and staminate spikelets of branch corn

FIGS. 92–94.—Inflorescences of suckers

The origin of the ear.—The structure of the ear is the distinguishing characteristic of the species; and around it and its homologue, the central spike of the tassel, have centered most of the theoretical considerations as to the origin of maize. The ear has probably been evolved from a pistillate panicle similar in form to the present staminate inflorescence. The loss of the lateral branches from this primitive structure was evidently correlated with the phylogenetic shortening of the internodes of the ear-bearing branch, and the consequent invagination of the inflorescence by the leaf sheaths, which are now the husks of the ear.

Distichism in the arrangement of the vegetative parts of the grasses is usually continued into the inflorescence, and this is to be regarded as a primitive characteristic. The paired spikelets of the branches of the tassel of maize, and in both the inflorescences of teosinté, are distichously arranged. But the same units in the ear and on the central spike of the tassel in maize are polystichous in arrangement, as are the branches of the tassels in both maize and teosinté. In the tassel of teosinté, there seems to be no true homologue of the terminal spike of the tassel in maize. The real problem, then, is reduced to an explanation of polystichism in the arrangement of parts around the central axis of the inflorescence.

Of the many attempts that have been made to explain, wholly or in part, the evolution of this peculiarity in the inflorescence, four or five have resulted in theories that may be cited as having made definite progress.

Among the first to give the matter serious attention was Hackel (71), who attributes the origin of the ear to a hereditary anomaly of the nature of fasciation. He

makes no attempt to show a definite homology between the new structure and the parent-type, and this is chiefly where his theory fails to give satisfaction. It discourages investigation without really explaining anything.

The next definite line of reasoning on the problem assumed that the ear had resulted from the lateral fusion during development of two or more pistillate spikes similar in structure to the distichous branches of the staminate inflorescence.[1] This theory is the prevalent explanation of the problem. Out of opposition to this theory developed the idea of the homology between the pistillate inflorescence and the terminal spike of the tassel,[2] and the fusion idea is generally held as a reasonable explanation of both structures.

If the theory were well founded, however, we should expect to find in the development of the structures in question some indication of their peculiar phylogeny, but such evidence is lacking. The young ear and the young tassel develop from ordinary growing-points with nothing to suggest a compound nature, and nothing to explain why their lateral ramifications are developed in several, instead of in two, rows.

But the weakest point in the theory is its failure to account for ears having rows not in multiples of four. Each spike contributing to the formation of the ear its two rows of paired spikelets would account for four rows of grains. Ears with eight, twelve, sixteen, or twenty rows of grains would be expected; but ten, fourteen, or eighteen rows would be impossible; and the frequency with which the latter numbers occur constitutes a serious inconsistency.

[1] Harshberger (74). [2] Collins (24) and Montgomery (110).

Another theory has the polystichous organ evolved from the upper part of a large, diffuse panicle, by the reduction of branches to pairs of spikelets.[1] The ear and the tassel of one peculiar variety of corn suggests this origin, and the theory seems consistent with all available facts.[2] But it falls short of a complete explanation, for it evades explanation of the origin of polystichism in this more primitive inflorescence.

A recent theory[3] suggests that the ear has resulted from the shortening and twisting of a two-rowed pistillate spike, accompanied by an increase in the number of pairs of spikelets, and by the yoking of adjacent pairs. This idea has some points in its favor, but it must be modified in some respects and supported by certain further observations before it can be accepted more than tentatively. It is unfortunately based upon the suggestive structure of the pistillate spikes of hybrids between maize and teosinté, and these are of doubtful value as indicating the character of either parent-genus. The corollary explanation of the structure of ears of corn with more rows at the base than at the tip is certainly untenable, being based apparently upon the external appearance of the mature ear, which is but a poor expression of the internal structure.[4]

The last word has not yet been said on the evolution of the ear of corn, and it cannot be said until further

[1] Collins (24). [2] See Figs. 86–91.

[3] Collins (30).

[4] The difference, when there is any, between the number of rows of grains at the base of an ear and the number at the tip is always a multiple of two, and there is no place on the ear at which an *odd* number of rows can be found in following around a circumference. Collins (30) attributes this to a sort of sympathetic "yoking" between each pair of spikelets and a pair almost diametrically opposite it on the ear. He states that the loss in number of rows noted in examining an ear from base to tip is due

researches have corrected, amplified, and evaluated the data now at hand, and woven the results into a harmonious fabric of theory.

These investigations will be made from many different points of view and along very different lines, and no small part of the task will be to sort out the significant from the irrelevant. The most fruitful field seems to be in a broad, yet detailed, study of the comparative morphology of the inflorescences of many grasses, with the results all referred back to the problems offered by maize. Anomalous inflorescences will doubtless contribute valuable information, but the investigator must avoid the common error of considering every anomaly a reversion.

Hybrids between maize and teosinté will always exhibit suggestive series; but, until we are more sure of the homologies between these two genera, it is futile to expect much information from the hybrids, for they will be speaking in a language that we cannot understand. When the true homologies of their inflorescences are clear, then these hybrids may afford checks upon our conceptions of morphology; but they will never alone constitute valid constructive evidence as to phylogenetic relationships or the course of evolution. Interaction between closely related entities is capable of giving rise to monstrosities that defy explanation in terms of the relationships of the parent-stocks; and only a sound working basis of morphology will save the investigator from the lure of suggestive analogy.

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to the dropping of one spikelet from each pair in a row of paired spikelets, and the simultaneous dropping of one from each pair in the "yoked" row of paired spikelets on the other side of the ear. But the writer has shown (156) that by shaving the chaff from the cob, as when a corncob pipe is to be made, it can be demonstrated that the loss in number of rows is really due to the dropping of an entire row of pairs of spikelets.

CHAPTER XV

SPIKELETS AND FLOWERS

The spikelet of any species of grass usually exhibits a limited range of variation. The general habit of the plant, the anatomy of its vegetative parts, and the size and form of its inflorescence may vary widely with environment; but, though a luxuriant specimen may have a thousand spikelets, and a depauperate individual of the same species but a single one, there is a tendency on the part of each species to maintain a high degree of uniformity in the structure of its spikelets. This gives to the spikelet a very considerable weight in the determination of the identity and relationships of the species.

The spikelet of a grass consists of an aggregation of flowers and bracts more or less compactly arranged alternately in two rows on a common axis, the *rachilla*. At the base of the spikelet is usually a pair of empty bracts, the *glumes*, and above these, one or more similar structures, the *lemmas*, the number of the latter varying with the species, and, to a certain extent, with conditions. From the axil of each lemma arises a short branch, bearing on its adaxial side a single bract, the *palea*, and terminated by a flower.

The flower consists of a pistil, one to six stamens, and two or three lodicules. The lodicules are probably the metamorphosed remnants of a perianth. Their function is to open the spikelet by forcing back the lemma at the time of flowering. Variations from this typical structure of the spikelet and flower can usually be attributed to the abortion of one or more parts.

A sharp line of distinction may be drawn between one group of genera, in which the spikelet is indeterminate, and another in which it is determinate. In the one, the lower flower is the most advanced in development, and abortion of parts is most likely to occur at the top; in the other, this order is reversed.[1]

It is among the grasses having determinate spikelets that maize finds its place. Both the staminate and pistillate spikelets are modifications of a two-flowered primitive type in which the upper flower is the more advanced in development, and in which certain parts are suppressed in development.

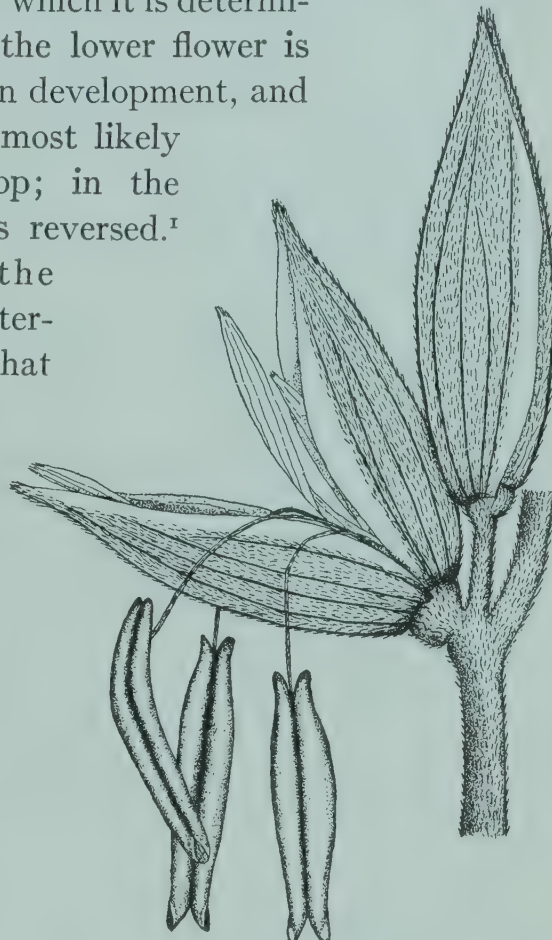


FIG. 95.—A pair of staminate spikelets

The staminate spikelet.—The staminate spikelet is a rounded, somewhat laterally compressed structure, borne with its edge toward the rachis. The other parts of the spikelet are completely inclosed, previous to flowering, by the two firm, ovate, overlapping glumes (Fig. 95).

[1] This is not an infallible mark of distinction between the two great subfamilies of grasses recognized in current systematic practice, but it is probably the most significant single point of variation in the family.

The lemma and palea are thinner and more abruptly pointed, or even rounded at the tip. The glumes are more or less pubescent, but the other bracts are glabrous. The rachilla is very short, and the upper flower is apparently terminal.

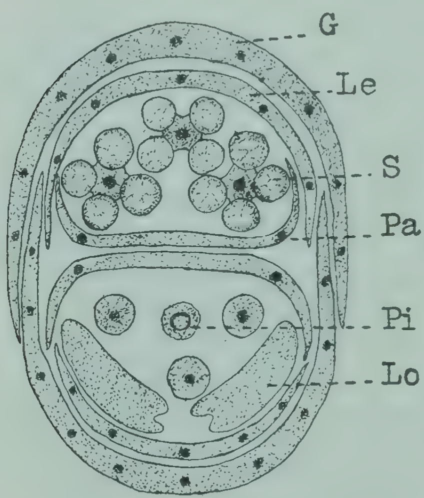


FIG. 96.—Diagram of cross-section of staminate spikelet. *G*, glume; *Le*, lemma; *S*, stamen; *Pa*, palea; *Pi*, pistil (rudimentary); *Lo*, lodicule.

In the flower proper, the three stamens are about equally spaced around the somewhat triangular receptacle, one being dorsal and the other two next to the palea. The two lodicules are located dorsally, alternating with the stamens. In the vascular system of the receptacle, there is a suggestion that the flower may at one time have had a third lodicule. In the middle of the receptacle is a rudimentary pistil (see Figs. 96 and 97).

The pistillate spikelet.—The parts of the primitive two-flowered spikelet have undergone much more modification in the pistillate than in the staminate spikelet. The glumes are thick and fleshy and do not completely inclose the other parts of the spikelet. Their pubescence is rudimentary. The lemmas and paleas are thinner and shorter than the glumes.

Normally, the only part remaining functional of either flower of this spikelet is the pistil of the upper

flower. Irregularly distributed around its base are three rudimentary stamens. The lodicules are seldom visible at anthesis. The entire lower flower is aborted, but the rudiments of its essentials are always present. The lodicules are usually much better developed than those of the upper flower, but they are apparently functionless (see Fig. 98).

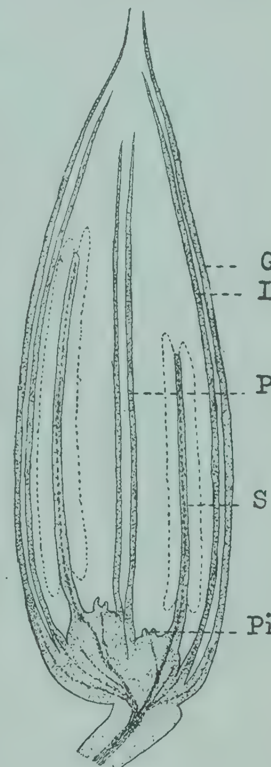
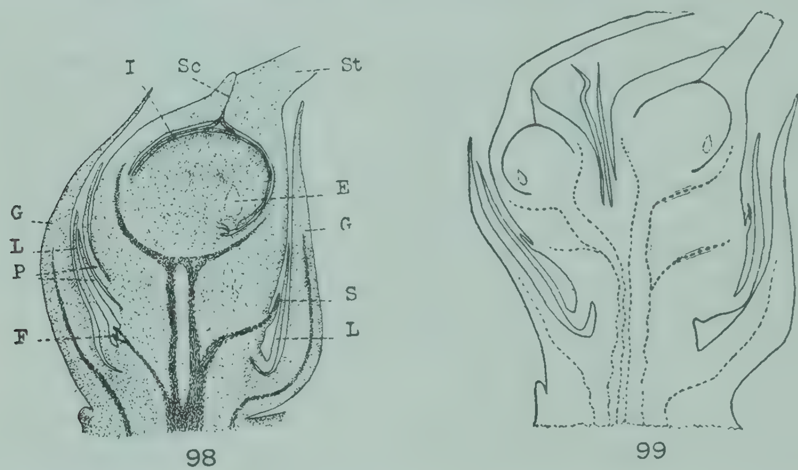


FIG. 97.—Diagram of longitudinal section of staminate spikelet. *G*, glume; *L*, lemma; *P*, palea; *S*, stamen; *Pi*, rudimentary pistil.

Sexual anomalies.—Most of the anomalies of the spikelet or of the flower are due to the functioning of some parts usually abortive. Those of commonest occurrence are perfect flowers, androgynous spikelets or pairs of spikelets, and spikelets of reversed sexuality.

Functionally perfect flowers are of rare occurrence. They are due to the development of either stamens in the ear flowers or pistils in the flowers of the tassel. The latter usually produce fruits (Fig. 72), and their silks are often divided into two distinct styles and stigmas, as was doubtless the condition in the prototype of maize. The stamens of perfect flowers in either the ear or the tassel may be normal, or they may show various types of abortion. Sometimes only one of the three stamens of a flower is functional, or even fully developed in form; and, in such cases, it is usually the dorsal one that makes greatest development.

In both inflorescences the metamorphosis of a spikelet is often a complete change of sex. When a tassel spikelet becomes pistillate, it often loses its stamens and influences the glumes and a section of the rachis to assume the characteristics of the pistillate axis. On becoming staminate, a spikelet of the ear assumes the staminate form of glumes, and elevates itself on a pedicel



Figs. 98–99.—Fig. 98, diagram of longitudinal section of pistillate spikelet. *St*, base of style; *Sc*, stylar canal; *I*, integuments; *G*, glume; *L*, lemma; *P*, palea; *F*, rudimentary flower; *E*, embryo sac; *S*, rudimentary stamen. Fig. 99, longitudinal section of the two-flowered spikelet of Country Gentleman sweet corn.

if it be potentially the pedicellate one of the pair. If enough spikelets in a group are thus metamorphosed, the rachis also assumes the character of the same structure in the tassel. If only one spikelet of a pair changes its sex, it is usually the sessile one of the staminate unit, and, almost invariably, the pediceled one of the pistillate unit, that is affected.

Compound spikelets.—Terminating any branch of the tassel may often be found an abnormal spikelet having

more than two flowers, and sometimes more than two glumes. A common form of the anomaly is a structure subtended by a whorl of three or more glumes. Dissection proves these anomalies to be due to the coalescence of two or more spikelets. They probably have no morphological significance.

Two-flowered pistillate spikelets.—Regularly in one or more varieties of sweet corn,[1] and occasionally in any variety of corn, both flowers of the pistillate spikelet are well developed, and two grains are produced in each. When this occurs throughout the ear, it doubles the number of grains on the cob and leads to the characteristic "shoe-peg" shape and irregular arrangement of the grains (Figs. 100 and 167).

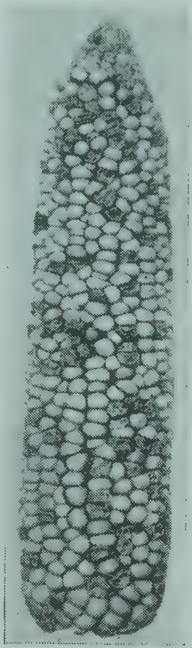


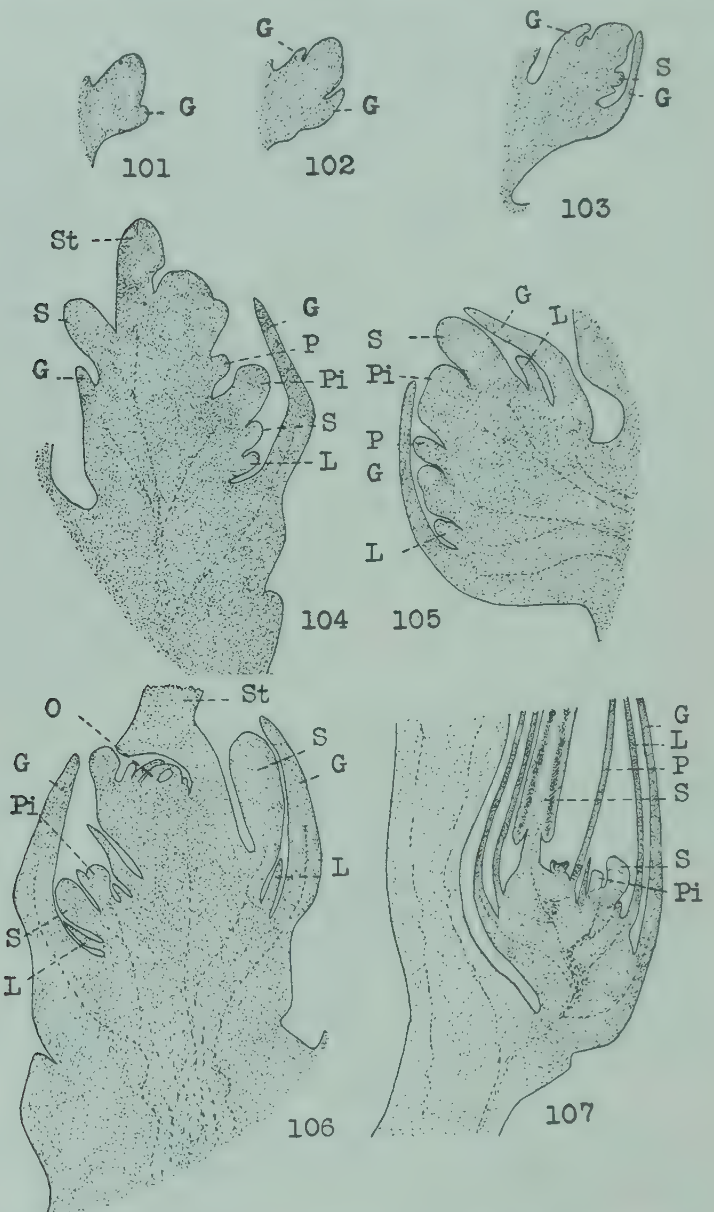
FIG. 100.—An ear of Country Gentleman sweet corn with many starchy grains due to xenia.

Development of the spikelets.—The similarity in structure between the pistillate and staminate spikelets is well brought out in their development (Figs. 101–7). At the time of their first appearance, the two types are exactly alike. The homologous parts of the two appear in the same order, and follow the same course in development, until they begin to diverge in appearance because of the suppression of parts.

The primordium of a pair of spikelets makes its appearance as a rounded protuberance on the floral axis.

[1] This is a regular occurrence in the spikelets of Country Gentleman and Ne Plus Ultra sweet corn.

This soon divides into two somewhat unequal parts, the primordia of the two spikelets. In each spikelet



FIGS. 101–7.—Sections of spikelets showing development: Figs. 101–3, spikelets undifferentiated as to sex. Figs. 104, 106, pistillate spikelets. Figs. 105, 107, staminate spikelets. *G*, glume; *S*, stamen; *St*, style; *P*, palea; *L*, lemma; *O*, ovule; *Pi*, pistil.

the lower glume is the first differentiation to appear, and it is soon followed by the upper glume, and this by the two lemmas. By a division of the growing-point, the meristematic region now develops a large upper lobe and a smaller lower one, the primordia of the two flower-bearing branches. On the upper one of these, the palea is soon differentiated, but that of the lower flower is late in making its appearance.

In the ontogeny of the flower, the stamens first appear, and then the lodicules; and the part that remains becomes the primordium of the pistil. The detailed aspect of each of these organs is dependent upon the kind of flower, staminate, or pistillate, in which it is developed.

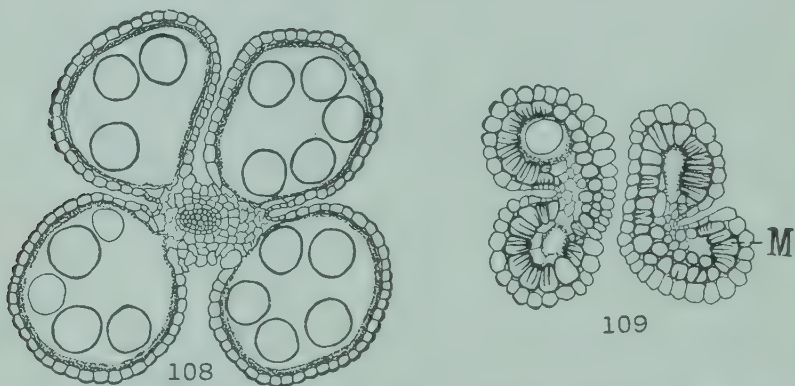
The two flowers of the staminate spikelet are alike in all homologous steps of normal development, but the upper is considerably in advance of the lower.

The development of the stamen offers no problems essentially peculiar to maize. Cross-sections of the anther at the time of the heterotypic division show the pollen mother-cells surrounded by three layers of tapetal cells. The subepidermal mechanical layer, instrumental in opening the anther, is present for only a short distance at the distal end of the anther (Fig. 109). As a result, the anther opens by only a small pore (Fig. 95). As the sporogenous tissue develops, the tapetum is absorbed until only the epidermis and mechanical layer are present at maturity (Figs. 108, 109).

The two small protuberances arising soon after the stamens, and alternate with them, develop into the lodicules. At maturity, these are usually short, plump, truncate bodies, but they often bear terminal leaflike appendages also. A generous quota of vascular tissue

enables them quickly to become turgid when they are called upon to play their part in opening the spikelet.

The pistil present in the young staminate flower varies somewhat in its method of development, but it seldom proceeds beyond the initial steps in the formation of the ovary wall. An archesporial cell may be differentiated sometimes, but as a rule this stage is not reached. Disorganization of this structure begins internally and proceeds to such an extent that at flowering time only



FIGS. 108, 109.—Cross-sections of a mature stamen. *M*, mechanical layer of cells instrumental in opening the anther.

a basal ring of the epidermis remains. By this time the whole structure is so inconspicuous that it is easily overlooked.

In the pistillate spikelet the only floral organ to reach maturity is the pistil of the upper flower, which develops from the meristematic region remaining after the differentiation of the stamens. At the base of this rounded protuberance, there arises a ring of tissue, which grows up on all sides and arches over to form the wall of the ovary. The edges of this layer of tissue come together at the top, but they never unite, and the small

stylar canal remains in the mature ovary. At the abaxial side of the stylar canal arises a small protuberance, which develops into the style and stigma, the well-known "silk" of the flower (Figs. 110–14, p. 124).

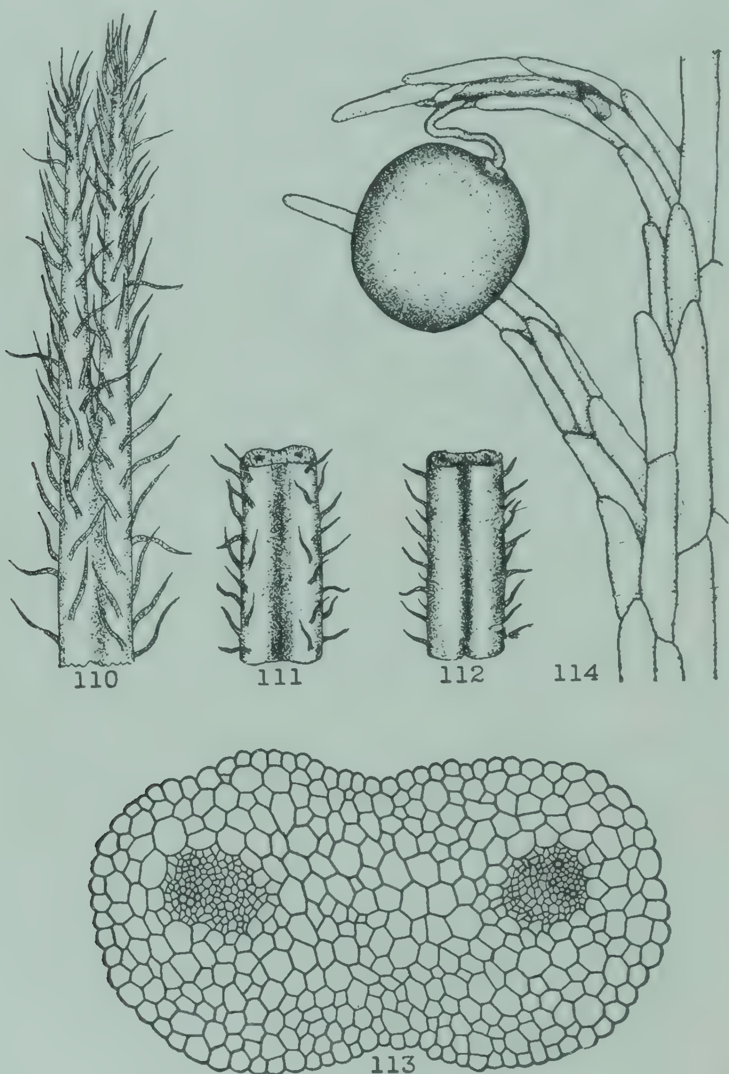
A cross-section of the style (Fig. 113) exposes the fallacy of the idea that it is a hollow tube. It is really a solid, flattened organ without internal cavity. For some distance at the tip it is divided into two parts, and the whole length is traversed by two grooves and two slender, poorly developed vascular bundles.

Pollen tubes usually gain entrance to the silk through the numerous hairs which give it its plumose appearance. Each of these hairs arises from an epidermal cell, which divides anticlinally into four cells. By transverse divisions these give rise to a tapering structure consisting of four rows of cells and having a longitudinal canal through the middle. It is by way of this canal that the pollen tube usually makes its way into the body of the silk.

The silk has evidently originated in the fusion laterally of the two styles and stigmas of a primitive pistil similar to that of the other grasses. This fusion probably resulted from the close contact of the two structures as they developed, phylogenetically, under the influence of the husks of the ear. The extraordinary length of the silk—as much as 18 inches in some varieties—is probably an expression of an attempt on the part of this organ to keep its tip exposed beyond the enveloping leaf sheaths. But the stigmatic portion of the silk is by no means limited to the part exposed beyond the husks; it is probable that all parts of it down to within an inch or two of the ovary are receptive to pollen. Growth of the silk usually stops as soon as it is penetrated

by a pollen tube, but, if it be protected from pollination, it may continue to grow for a long time.

From the small meristematic protuberance remaining inside the ovary after the development of the wall of



FIGS. 110–14.—Fig. 110, tip of the silk with stigmatic hairs. Figs. 111, 112, segments of the silk at some distance from the end. Fig. 113, cross-section of the body of the silk. Fig. 114, pollen grain germinating on a stigmatic hair.

the latter, the ovule develops. Shortly before the archesporial cell is differentiated, the two integuments appear as rings of tissue at the base of the ovule. By a very rapid adaxial growth, the whole ovule next proceeds to invert itself, finally assuming a form somewhere between the anatropous and the campylotropous. It is attached along one side and has no funiculus, but the embryo sac and embryo remain straight. The outer integument usually does not cover the ovule completely, its edge being caught in the stylar canal as it grows over the nucellus. The nucellus protrudes through the large micropyle. The integuments are, for the most part, only two cells in thickness, and their development stops at about the time of fecundation. This aborted nature of the integuments seems to be characteristic of the grasses. It has doubtless arisen as a correlation with the closely investing pericarp. The mature embryo sac occupies a very small space at the abaxial side of the nucellus.

Although the ovary in all species of grasses is unilocular, there are indications that the pistil is composed of three carpels.[1] This is especially evident in many genera often having three styles; and in others, including maize, it is shown by the vascular system. Of the three vascular strands that enter the base of the pistil, two pass into the style and one into the base of the ovule. The evolutionary changes leading to this condition have never been investigated, but the tricarpellary nature of the pistil is another link in the connection between the grasses and other monocotyledonous plants.

The abortive stamens at the base of the functional pistil are dwarfed during development, and are not

[1] Walker (144).

distinctly differentiated into anther and filament. They make an effort, however, to produce pollen, and the microspore mother-cells are often differentiated before disorganization begins. Like the aborted pistil of the staminate flower, these stamens begin to disorganize internally, and the epidermis is the last to go. All that remains at anthesis is a basal ring of the epidermis, or at most, the minute, shriveled epidermal shell.

In the lower flower of the pistillate spikelet, the stamens meet with the same fate as those of the upper flower, and the pistil shows the same steps of development and decline as that in the staminate flower.

CHAPTER XVI

POLLINATION

A consistent correlation exists between structure and function of the parts of the maize plant concerned in pollination; but no encouragement is offered to birds or insects as agents of pollination. English sparrows often strip the tassels of their staminate flowers, but their depredations usually occur before the time of pollination. Ants wander over the plants, aimlessly, or looking for aphids, but their influence is negligible. Bees collect large quantities of pollen and carry it away, and many insects visit the pistillate branch to lay their eggs or eat the silks; but no insect seems to find it profitable to visit both inflorescences at the right time to have any influence on pollination.

FIGS. 115, 116.—Effects of incomplete pollination.

Agencies.—Practically the only agencies actively concerned in the transfer of pollen are gravity and the wind, and the plant is well adapted to these agencies. The tassel, held high in the air, showers down its abundance

of dustlike pollen over a long period of time; and each pistillate flower, at a lower point on the stem, exposes a maximum of stigmatic surface armed with viscid hairs.

The smooth, round pollen grains, with their dry external surfaces, have a minimum tendency to stick to one another or to the leaves and stem of the plant, and they are easily carried by the wind.

Although most of the pollen of a single plant is usually scattered over only a few square feet, it may, in a high wind, be carried as much as a quarter of a mile.

Duration.—A number of factors combine to lengthen the period during which the pollen is being shed from a single inflorescence. The upper flower of a spikelet usually reaches maturity a few days before the lower, and there is sometimes a noticeable difference in the time of opening of the sessile and pediceled spikelets of a single pair. The oldest flowers are in the upper, and the youngest in the lower part of the tassel. Anthesis begins at some distance from the end of the central spike and proceeds upward and downward. A little later, the spikelets near the ends of the uppermost branches begin to open, and a wave of maturity passes down all the rachids at the same time. Before the upper florets of the lowest spikelets are shedding pollen, the lower florets of the upper ones have begun to open, and a second wave of maturity passes downward. The flowering of a single tassel may extend over a period, varying with conditions and the size of the inflorescence, from two or three days to as much as two weeks in length.

As a rule, both cells of the anther open at the same time; but, because of the limited size of the pore, the pollen is not all discharged at once. The process may

require several hours, but it is usually accomplished in a single day. The florets begin to open soon after sunrise in favorable weather, and by the middle of the forenoon the air in a field of flowering corn is full of pollen; by noon most of the pollen is shed for that day.

The opening of the floret and the exsertion of the anthers is accomplished very quickly, actual movement of the parts often being visible under slight magnification. The sudden gorging of the lodicules with water and the elongation of the filaments seem to be amenable in a large measure to environmental influence, the optimum conditions being afforded on a warm forenoon just following a rain.

Receptivity of the silk.—In the pistillate inflorescence, as has been noted, the oldest flowers are at the base and the youngest at the tip. The period between the emergence of the first and last silks may be as much as a week; but, because of the greater length to be attained by the former, this difference in time is usually reduced to two or three days. The silks are receptive as soon as they emerge from the husks, and the period of receptivity continues for two weeks or more, the silks continuing to elongate, in the meantime, if they are not pollenized.

Abundance of pollen.—In all wind-pollenized plants much pollen is wasted, but ample allowance is made for this in maize. A single anther produces about 2,500 pollen grains, and a single spikelet about 15,000. The staminate spikelets are usually far more numerous than the pistillate, the ratio sometimes being as great as 10 to 1; and each pistillate spikelet requires but a single pollen grain. The ratio between supply and demand

may, therefore, be a great as 150,000 to 1; and a ratio of 10,000 to 1 probably occurs in most varieties.

Dichogamy.—Inflorescences bearing flowers of both kinds are definitely protogynous, the silks usually preceding the pollen long enough to make self-pollination within the inflorescence impossible. These mixed inflorescences behave, therefore, much the same as ordinary tassels or pistillate units in pollination.

Although the individual inflorescence is protogynous, the plant, as a whole, is usually protandrous, due to the fact that the tassel is more advanced in development than the ear, the former being staminate and the latter pistillate.

Protandry is by no means complete, however, and the shedding of the pollen and the receptivity of the silk usually overlap sufficiently to make a limited degree of self-pollination a thing of normal occurrence, and complete self-pollination an experimental possibility. In a few varieties protogyny normally occurs regularly.

Significance of cross-pollination.—In view of the pronounced effects of inbreeding in maize, the normal tendencies of the plant at the present time, and the conditions to which it has been subjected in the past, become significant matters.

Self-pollination is seldom completely prevented by a difference in the time of maturity of two inflorescences of the individual plant; but cross-pollination is usually necessary for the production of well-filled ears, as is shown by the ears of isolated plants. The extent of self-pollination, under normal conditions, cannot be determined by the extent to which it occurs in isolated plants, for a complication is introduced by the massing

of plants. The extent of self-pollination depends not upon the number of the plant's own pollen grains that *ultimately* reach its silks, but upon the number that get there *ahead of all others*.

The meager data now at hand indicate that, under ordinary field conditions, where the plants are grown in clumps of three or four, self-pollination occurs in only about 5 per cent to 10 per cent of the seeds. All that we know of the agriculture of the Indians indicates that the growing of corn in hills has been practiced for centuries by practically all tribes of both continents. The limitations of the aboriginal methods of cultivation made this a profitable method of planting, and the number of plants grown in a hill was often as high as ten or twelve. This massing of plants was a decided encouragement to cross-pollination, and the selective effect of this condition has probably been the active factor concerned in the development of the intolerance of self-fertilization.

CHAPTER XVII

GAMETOGENESIS AND FECUNDATION

At flowering time of the maize plant, a striking picture is presented by the expanded tassel, releasing its shower of pollen to be received by the conspicuous tuft of silks below. But these readily visible features are merely accessory to certain fundamental processes revealed only now and then under high magnification and in response to special technique.

The pollen grain that falls on a silk has had a significant past and is to have a short but active future; and the silk itself leads the way down to the culmination of one of the most peculiar occurrences of cellular activity known anywhere in the kingdom of living things. The end of the whole process seems to be the production of certain sexual cells and the methodical union of these cells to form the beginnings of a seed, the forerunner of a new generation of the plant.

Each pollen grain is to produce two sperms, together with the apparatus for conducting them to the ovule and into the presence of two other cells of gametic nature. One of these, the egg, is definitely female; but the other, the endosperm cell, is of doubtful nature sexually. In the union of one sperm with the egg is the origin of the embryo of the seed, and the endosperm arises from the fusion of the other sperm with the endosperm cell.

The details of the events leading to the formation of the gametes and to their union in fecundation are of

great theoretical importance in all organisms; but certain consequent hereditary phenomena, which find their most significant expression in maize, render the process unusually interesting in this plant.

The pollen grain.—Early in the development of the anther, the four sporangia are differentiated, each containing its long column of sporogenous tissue surrounded by tapetal layers. A time soon comes when the sporogenous cells cease to divide in the ordinary way, but they continue to grow rapidly at the expense of the surrounding tapetum. These become the pollen mother-cells.

The heterotypic division takes place quickly, and the small, short chromosomes are observed with difficulty in the dense cytoplasm. Even the number of chromosomes is a matter of some doubt. The most extensive observations that have been made on this point indicate a variable number, with ten predominating in the starchy varieties and twelve in the sweet varieties as the haploid number. But accompanying these apparent variations in number is a variation in the size of the chromosomes; and this, together with the difficulty of observation and the uncertainty in distinguishing large chromosomes from groups of smaller ones, leaves the actual variation in number open to question. The results obtained in attempts to count the diploid number in vegetative cells have been little more satisfactory. Here the chromosomes are long and twisted and indistinct. The relative instability of varieties of maize, and the lack of consistently correlated differences between sweet and starchy varieties, makes it essential that the fact of a consistent difference in the number of chromosomes be

firmly established before it be made the basis of any extended theoretical consideration.

Immediately following the reduction division, the two daughter-cells divide homotypically, and the four cells of the tetrad round off and proceed to mature into pollen grains. Two more nuclear divisions occur, and a thick wall with a conspicuous germ pore is formed, before the pollen grain is ready to leave the anther. The details of these latter steps in maturation have never been observed.

At maturity the pollen grain is almost spherical, but this shape is sometimes modified by the effect of pressure of other spores during development, and by shrinkage due to desiccation. The thick exine is minutely tuberculate. The intine is thin except for a ring around the germ pore. The cytoplasm is so dense as to make observation of other contents of the spore very difficult. The vegetative nucleus is poorly organized (Fig. 118).

At the time of leaving the anther the mature pollen grain contains the fully developed sperms.[1] These are two small, crescent-shaped cells with long attenuate ends. The nucleus, which seems to be a compact mass of chromatin, constitutes the greater part of the sperm.

The pollen tube.—The pollen grain of maize has the task of producing one of the longest pollen tubes known in the plant kingdom. For this it is provided with a rich store of food, later to be supplemented by a supply

[1] Some authorities state that the sperms are not formed until after the emergence of the pollen tube, but improved technique shows this idea to be incorrect. See Andronescu (3).

drawn from the style upon which it feeds. In their compact structure, the sperms are well adapted to their long journey from the pollen grain to the embryo sac.

Pollen grains may be germinated in various nutrient media, but their normal behavior is readily observed while they are growing on the silk. The stigmatic hairs of the silk are apparently covered with a viscous substance which holds the pollen grains and probably stimulates them to the first steps of germination. Under favorable conditions, germination may begin and the pollen tube become well established in the silk in as short a time as two hours.

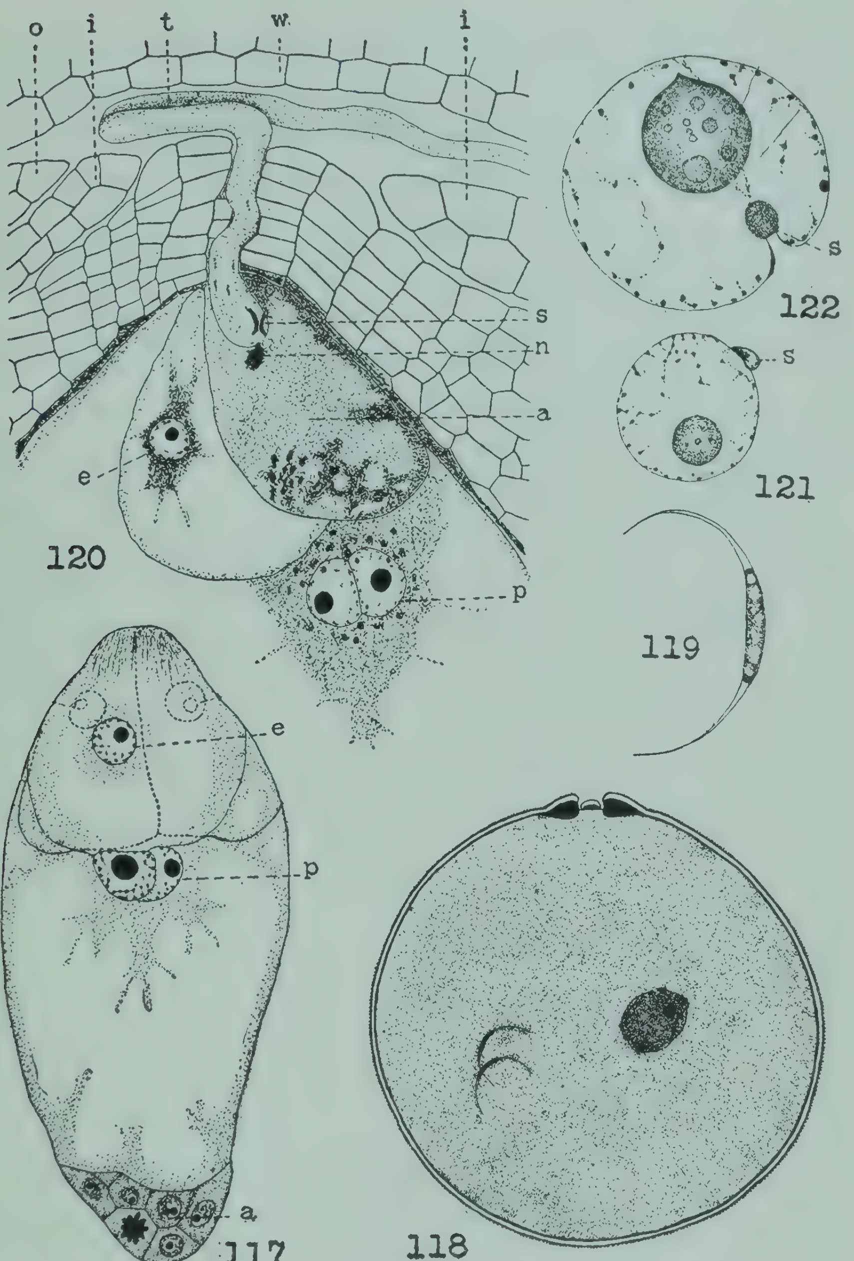
The tube emerges from the pollen grain by way of the germ pore and usually enters the silk through one of the hairs of the stigma (Fig. 114, p. 124). It may, however, enter the body of the silk directly. Once inside, it makes its way through the parenchyma to one of the vascular bundles, from whose richly stored sheathing elements it absorbs nourishment as it proceeds toward the ovule. Growing at one end and dying at the other, the tube makes its way downward; and, although the total distance trasversed may be considerably more than a foot, probably much less than an inch of the tube is ever really alive at any one time. Its growth is so rapid that, under favorable conditions of temperature and humidity, fecundation follows pollination within twenty-four to thirty-six hours.

It is a well-known fact that the period of pollination constitutes a critical phase in the life-cycle of the plant. Many Indian tribes in prehistoric times had elaborate religious ceremonies designed to bring the crop through this crisis, and the observant farmer well knows that his

crop is often made or lost by a warm shower or a few hot, dry days when the corn is in silk. This critical period is probably attendant upon the germination of the pollen grain and the establishment of the tube in contact with a permanent supply of moisture in the silk. Although the tube is exposed to the air for only a few minutes while passing from the pollen grain to the stigmatic hair of the silk, yet its diminutive size and delicate structure render it very susceptible to desiccation; and this step in the process usually takes place during the warmest part of the day. The pollen grain itself, being viable for only a day or two, under the best of conditions, is susceptible to injury from this same cause; but the importance of this factor is minimized by the short time required on the very direct route from the anther to the stigma.

The pollen tube has no fixed pathway after reaching the ovary. It seems certain that it does not, as some have supposed, leave the body of the style to enter the ovary by way of the stylar canal. It usually follows the vascular tissue well down along the side of the ovary before entering the ovarian cavity. Entering the ovule by way of the micropyle, it crowds its way between the cells of the nucellus and empties its contents into the embryo sac near the egg (Fig. 120).

The megaspore and embryo sac.—Soon after the appearance of the integuments of the developing ovule, the archesporial cell is differentiated just beneath the epidermis of the young nucellus. By a periclinal division, this cell gives rise to an outer tapetal cell and an inner megaspore mother-cell. The former is immediately absorbed by the latter, which undergoes a period



FIGS. 117–22.—Fig. 117, mature embryo sac. Fig. 118, section of mature pollen grain. Fig. 119, sperm. Fig. 120, entrance of pollen tube into embryo sac. Fig. 121, fecundation of the egg. Fig. 122, fecundation of the endosperm nucleus. *o*, outer integument; *i*, inner integument; *t*, pollen tube; *w*, wall of the ovary; *s*, sperm; *n*, vegetative nucleus of pollen tube; *e*, egg; *p*, polar nuclei; *s*, synergid.

of growth before dividing again. The parietal layer of tissue, several cells in thickness, which finally separates the embryo sac from the epidermis, is produced from epidermal cells by periclinal divisions.

Following the heterotypic division of the nucleus of the megaspore mother-cell, a wall is laid down dividing the cell. By a homotypic division, the inner one of these cells divides again, producing two megaspores. The outer one also begins to divide, but this act is usually arrested by the beginning of a process of disorganization, which soon includes the adjacent megaspore, leaving only the more deeply seated megaspore.

The persistent megaspore now enlarges, absorbing the disorganizing sporogenous cells and the surrounding tissue of the nucellus. At the same time the nucleus begins a definite series of divisions, resulting finally in eight nuclei. The two nuclei produced by the first division move to opposite ends of the enlarging cell, and each divides again. One of the new nuclei at the micropylar end of the cell next divides, forming the nuclei of the two synergids; and the other divides to form the egg nucleus and one polar nucleus. Meanwhile, at the other end of the developing embryo sac, one nucleus has divided to form two antipodal nuclei, and the other to form one antipodal and one polar nucleus.

When these divisions are completed and eight nuclei are present, membranes are formed, cutting off the cells of the egg apparatus. At the same time, the walls of the antipodal cells are formed, and the two polar nuclei approach each other in the large cavity of the endosperm cell. Their actual fusion is delayed, however, until the time of fecundation.

As in other grasses, the antipodal cells begin vegetative division as soon as they are formed, and fifty or more may be present when the embryo sac is mature (Fig. 117).

Development of the pistil.—Although the developing embryo sac has increased greatly in size, both before and after its organization, it has not kept pace with the nucellus; and at maturity it occupies only a small part of the interior of the ovule. It is not until the embryo sac has completed its development that the style and stigma have made sufficient development to be partly exposed beyond the husks and ready for pollination.

Fecundation.—The entrance of the pollen tube into the embryo sac usually destroys one or both synergids, and in the resulting cytoplasmic confusion the sperms are followed with difficulty. It has long been accepted as a fact that one sperm unites with the egg to form the forerunner of the embryo; and, because of its genetic importance in connection with the occurrence of xenia, the fate of the other sperm has been a matter of considerable interest since the discovery of "double fecundation" in some other plants. It has now been fully demonstrated that this sperm unites with the two polar nuclei, giving rise to the endosperm of the seed.[1]

The significance of this sexual, or pseudo-sexual, origin of the endosperm, which seems to be of common occurrence among the angiosperms, is a morphological mystery. What the general interpretation of the phenomenon is, and how maize elucidates and yet complicates the problem, will be brought out in a later discussion of heredity in the endosperm.[2]

[1] Lee Guignard (70), Weatherwax (154), and Miller (109).

[2] See chap. xxiii.

CHAPTER XVIII

THE FRUIT

The loose definition of the word *fruit* permits its application to either the ear or the individual grain of maize. In the strictest sense, the grain is the fruit, for it is the structure developed from the ovary as a result of fecundation. But the compact nature of the ear, which is a matured inflorescence, makes it convenient, and entirely consistent with recognized terminology, to call it a multiple fruit.[1]

Many details of the ear are inseparable from those of the pistillate inflorescence and have been treated in an earlier description.[2] The ear is characterized by as great a range of variation as is shown in other parts of the plant, and this variability is the basis upon which the improvement of agricultural varieties has usually been accomplished.

Structure.—The axis of the ear is commonly called the *cob*.[3] It has the essential characteristics of a section of the stem, but its nodes are so close together that the identity of the internodes is lost. The central portion of the cob is a soft, white pith without vascular bundles, the latter being located in the peripheral layer of hard, woody sclerenchyma. The chaffy covering is made up of the bracts of the spikelets.

[1] Technically most like a *sorosis*, although the axis is not succulent as in the typical sorosis.

[2] See chap. xiv.

[3] By analogy the word *cob* would be correctly applied to the whole fruit, and European writers so employ it. But usage in America is as here indicated.

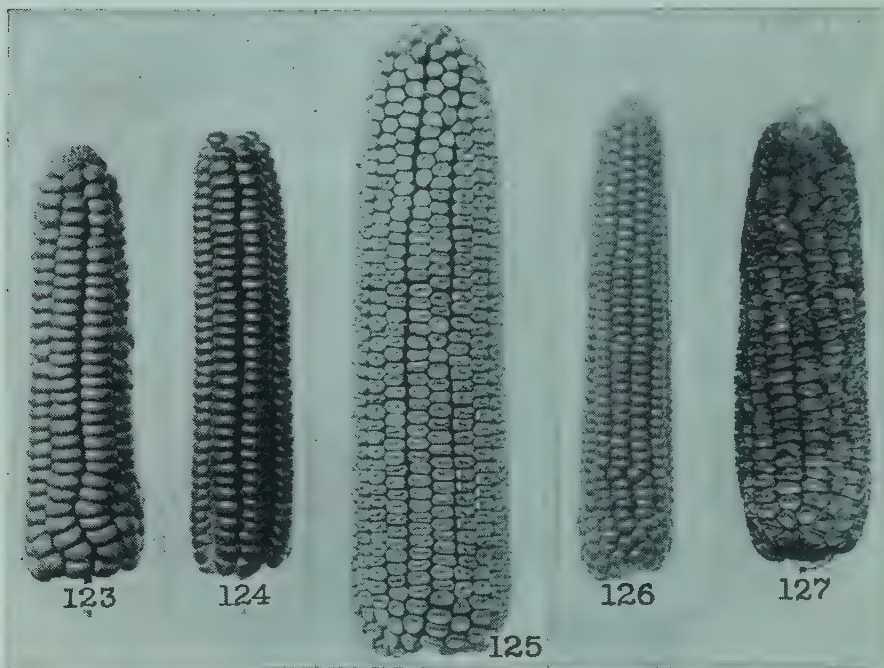
The grains are so arranged on the cob that the embryo of each is turned toward the tip of the ear. Because of the peculiar nature of the pistillate spikelet, half of the grains on an ear of Country Gentleman sweet corn are usually turned so that the embryos face the base of the ear, and an occasional grain in any ear may be so turned.

The number of rows of grains varies from four to thirty or more. The constantly even number of rows is explained by the fact that the structural unit is a pair of rows borne in a row of paired spikelets (Figs. 76, 77, p. 104). The discontinuance of one or more of these rows of pairs is responsible for occasional differences of two, four, or even more rows between the tip and the base of the ear. Four-rowed ears are rare; six-rowed ears have never been known to occur; and eight is the smallest number of rows commonly encountered.

Size and shape.—Ears range in length from 1 inch, in some of the South American pop varieties, to 20 inches, in some of the more vigorous flints and dents. The absence of any consistent correlation between length and diameter makes possible a multitude of shapes. There is a natural tendency for the ear to taper gradually from the base to the tip, due to a progressive decrease in the size of the cob and the grains, to closer crowding, or to the loss of two or more rows. Some of the short, conical ears of varieties grown in the Andes are borne in pistillate branches wholly out of proportion to the diminutive size of the ear. (Some types of ears are shown in Figs. 123–34.)

Show corn.—Dent corn is the standard type throughout the Corn Belt. The ideal ear has been agreed upon by growers, and the judging of show ears has been

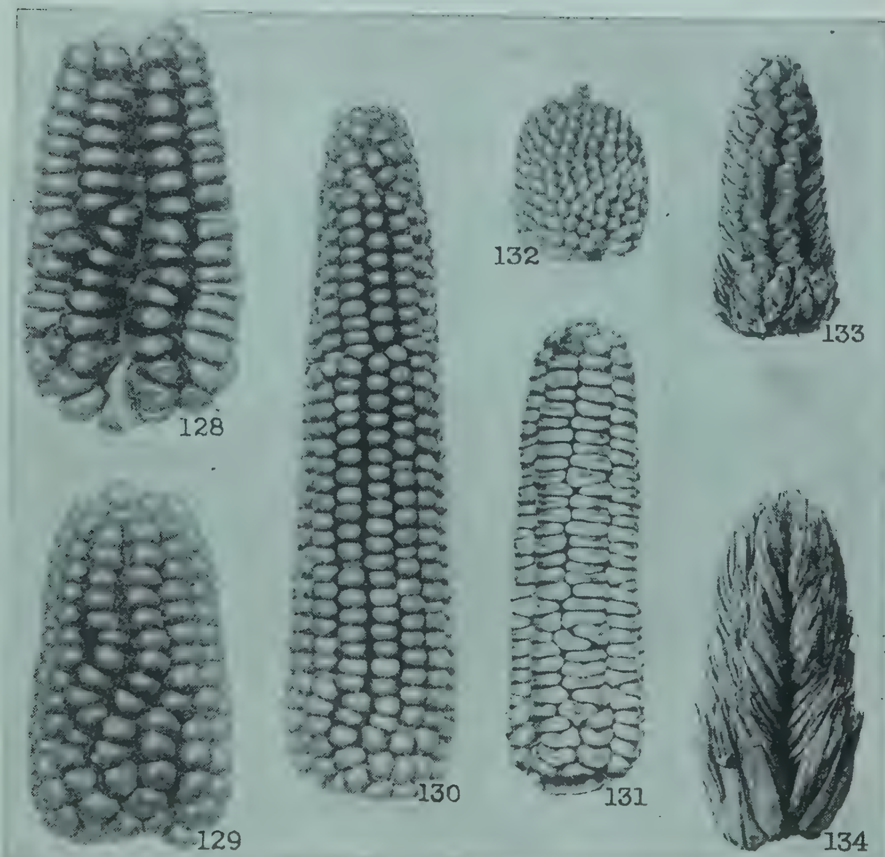
developed to a high degree of accuracy. The production of the ear or ten-ear exhibit that is awarded a state championship is no insignificant achievement; and the national championship, which is conceded to be the world-championship, is a goal too mean for the aim of none.



FIGS. 123–27.—Ears of the endosperm varieties, soft, flint, dent, pop, and sweet, respectively.

The ideal ear of dent corn is from 8 to 10 inches in length, depending upon the variety and the section in which it is grown. Its greatest circumference, which is near the middle, is three-fourths the length; from this it tapers very slightly to the base, and a little more to the tip. The base and tip are well filled with grains of good size and shape. A swollen base with a large area of attachment to the shank is undesirable. A pronounced conical shape, or a short portion of unfilled

cob at the tip, is sufficient for disqualification. The number of rows is from 18 to 24; these must be straight



FIGS. 128–34.—Figs. 128, 129, ears of varieties common on the western slope of the Andes. Fig. 130, a conical type of ear grown in many places where careful breeding is not practiced. Fig. 131, type of what was probably the best dent corn grown in America in pre-Columbian times. Fig. 132, short, thick ear of a pop variety. See also Fig. 71. Figs. 133, 134, pod corn

and uniform, and must continue for the full length of the ear.

The depth of the grain is dependent in a measure upon the variety, but the weight of the shelled grain is about four-fifths that of the whole ear. The dent in

the grain must be characteristic, any tendency toward a glassy smoothness being especially undesirable.

The grains must be clear and uniform in color. Grains off color because of mixture with other varieties count off heavily in scoring. The cob must be white in white varieties, and bright red in yellow varieties.

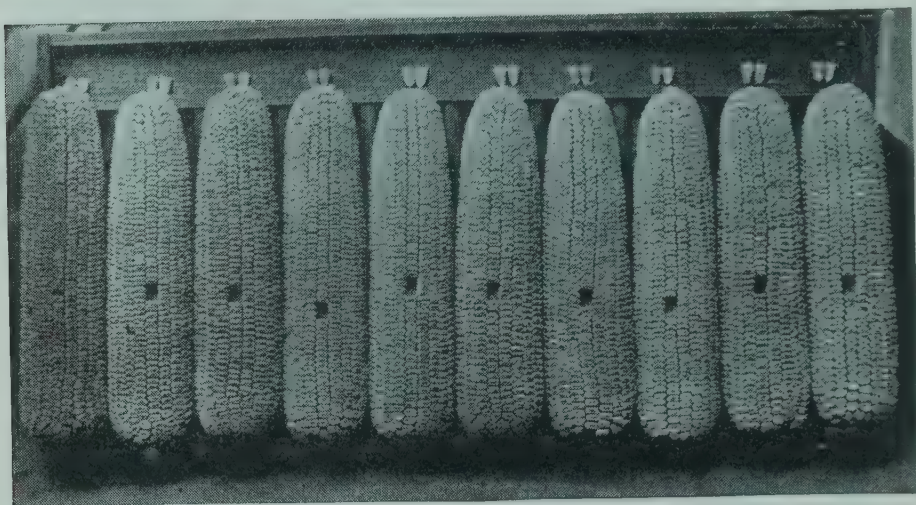


FIG. 135.—A prize-winning exhibit of dent corn. (These ten ears were awarded grand sweepstakes in a field open to the world, at the International Grain and Hay Show, at Chicago, 1920. Grown by C. E. Troyer, La Fontaine, Indiana. Photograph by courtesy of A. F. Troyer.)

Special classes are sometimes provided for mixed varieties and for a widely distributed white variety having a red cob.

Some dent varieties varying widely from these specifications are extensively grown; but they, like other varieties than dent, seldom enter the show ring in the Corn Belt except under special conditions.

Pod corn.—As an agricultural curiosity without economic value, pod corn is grown occasionally by students of the plant all over the world. In this variety

the bracts of the pistillate spikelet are so well developed that they form a tiny husk covering each grain (Figs. 133, 134). The whole ear is also covered by the normal husks.

Pod corn is not a variety distinct from all others. The character of its grains makes it amenable to classification among the dent, flint, pop, sweet, or soft varieties; and its other characteristics are as little its own exclusively, with the possible exception of the tendency to bear pistils in its tassels.

The caryopsis.—A grain of corn is an object of very great interest both economically and theoretically. Affording the largest and most easily dissected specimen of the caryopsis, the characteristic fruit of the grasses, it is much used for illustrative purposes in textbooks. The variability and peculiar origin of the endosperm of its single seed introduce complicated problems of heredity that have given the plant a prominent place in the research of the last two decades. As the storehouse of most of the food elaborated by the plant during its life, the fruit is the key to the important rôle that maize has played, and is still playing with daily increasing importance, in the economic life of humanity. Modern milling processes and feeding practices are carried on with a success proportionate to the account that is taken of the physical structure and chemical composition of the various parts of the caryopsis.

As has previously been stated, a grain of corn consists of three essential parts. The part for which all the rest of the grain exists is the embryo—the young corn plant in a dormant condition. This consists of a bud, a lateral cotyledon, and the primordium of a root. The

embryo is embedded in the side of the endosperm, a mass of tissue rich in proteins and carbohydrates. Surrounding both of these parts is a tough, fibrous hull, consisting of the testa and the pericarp.

The rôle of these parts in germination has already been described, but they have had a past, even as they are to have a future, and this will now be taken up in some detail.

CHAPTER XIX

THE EMBRYO

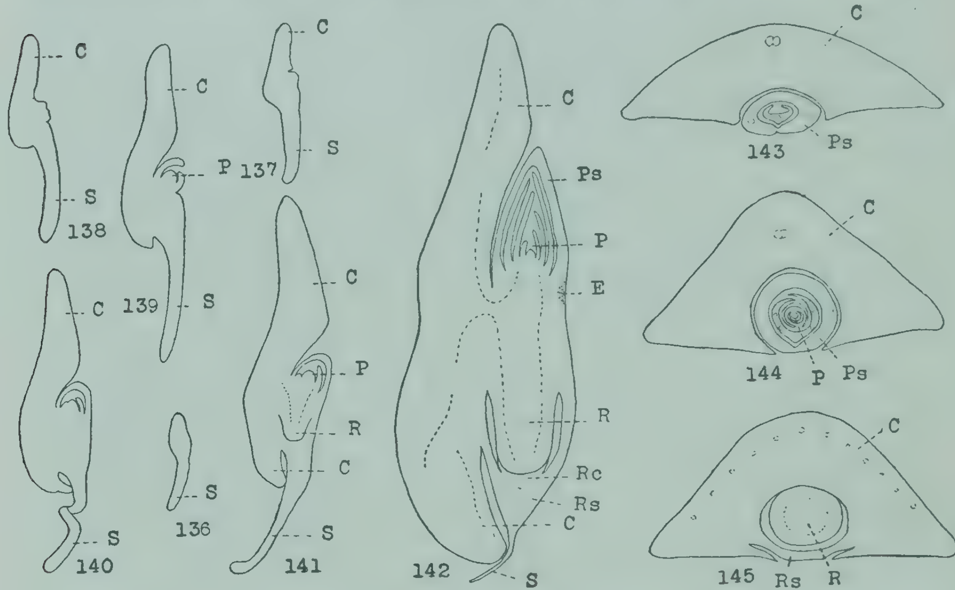
When the identity of the sperm has been lost in the egg, fecundation may be said to have been completed and the embryonic life of the new individual to have begun. The young zygote resembles so closely an unfertilized egg that the two are distinguishable only with the aid of secondary evidences of fecundation, such as the presence of remnants of a pollen tube, the destruction of the synergids, or the beginning of division in the endosperm cell.

The young embryo develops slowly. Several hours after fecundation, the fertilized egg cell is divided by a transverse wall into two very unequal cells. The smaller, which has a very dense cytoplasm, is to develop into the persistent parts of the embryo. The larger, whose cytoplasm is vacuolate, is the forerunner of the suspensor, the rapidly growing, temporary structure that forces the developing embryo into the endosperm.

Differentiation.—Symmetrical development of the body of the embryo ensues for only a short time before the cotyledon begins to differentiate as a lateral lobe. When this structure has developed far enough that its lateral position is evident, the plumule arises in a morphologically terminal position (Figs. 136–42). The coleoptile, which is the first part of the plumule to appear, arises as an open sheath, whose edges are later completely united. Inside of this sheath, the primordia of several

foliage leaves, and sometimes one or more axillary buds, are developed before the maturity of the seed.

Next in order, the cylindrical primary root is split out of the body of the axis of the embryo, between the plumule and the suspensor. From the tissue left surrounding the root proper, the root cap is later split



FIGS. 136–45.—Figs. 136–41, longitudinal sections showing development of the embryo. Fig. 142, longitudinal section of mature embryo. Figs. 143–45, transverse sections of mature embryo through different regions. *C*, cotyledon; *S*, suspensor; *P*, plumule; *R*, root; *Ps*, plumule sheath (coleoptile); *Rs*, root sheath (coleorhiza); *Rc*, root cap; *E*, meristematic rudiment of a second cotyledon.

off, and the remaining sheathing portion constitutes the coleorhiza. Three or more secondary roots are later differentiated from the central cylinder of the axis of the embryo, near the point of attachment of the cotyledon, and from the cortex a cap is split off for each root and carried outward on the end of the latter at the time of germination of the seed.

Meanwhile the suspensor has developed to several cells in thickness and has kept increasing in length fast enough to keep the cotyledon at all times well in contact with the endosperm. The pressure exerted by the growth of the suspensor is great, as is often shown by its contorted shape (Fig. 140). Almost opposite the cotyledon there is often seen a region of embryonic tissue, which is doubtless the equivalent of the epiblast of some other grasses. This is evidently the rudiment of another cotyledon.

Pseudo-polyembryony.—Actual polyembryony has never been reported in maize. The *appearance* of this phenomenon, in rare instances, is due to the duplication of the central axis of the embryo, resulting in the production of two, or very rarely three, plants by only one seed. The infrequent occurrence of this anomaly seldom gives a botanist opportunity for examining such material, and cases of true polyembryony may yet be discovered.

Nodes of the embryonal axis.—Notwithstanding some opinions to the contrary, the embryo affords very suggestive evidence of a previous dicotyledonous condition. The functional cotyledon is apparently located at the first node of the plant, the rudimentary cotyledon at the second, the coleoptile at the third, and the first foliage leaf at the fourth.

CHAPTER XX

THE SEED COAT

The protective covering of the grain of corn consists of the *testa* and the *pericarp*. The former is the remnant of the integuments of the ovule; the latter is the wall of the matured ovary.

The part played by the integuments is apparently of little importance, and they are never very well developed. After fecundation, they degenerate and are ultimately crushed to a thin, disorganized layer by the growth of other parts of the fruit.

Development of the pericarp.—During the initial steps in the formation of the embryo, the cells of the ovary wall continue to divide and increase in size. As the fruit nears maturity, these cells cease to divide, and their walls begin to thicken. Increase in size of the pericarp from this time forward is accomplished by the stretching of the tissues already formed. Its tardy development, at all stages, keeps it in a constant state of tension and gives it its tough, fibrous nature in the mature form. The tension at maturity is often great enough to cause the pericarp to split and the endosperm to protrude.

Layers of the pericarp.—The subepidermal portion of the pericarp consists of two rather definitely separated layers. These are much the same in structure, except in the region of the point of attachment of the grain. Here the outer layer is histologically modified as it continues downward, forming the spongy pedicel of the fruit. The inner layer becomes densely pigmented with brown

or black just opposite the end of the scutellum as the fruit approaches maturity.

This pigmented spot is present in all varieties of maize, as well as in many other grasses. The two layers of the pericarp seem to be loosely held together opposite this pigmented area, which is easily exposed by breaking off the pedicel of the grain. Grains that are diseased, or improperly matured, often break off at this surface on being merely shelled from the cob, this occurrence giving rise to the common impression that the black spot is an abnormal thing, the result of disease. But the spot itself is normal; it is only its revelation under these conditions that is an indication of an abnormal physiological condition.

Color.—The color of the pericarp may be a light yellow or cream, but it is seldom, if ever, a pure white. A pericarp, seeming to be white when underlaid with a white, floury endosperm, will show a decided tint when seen against a background of corneous white endosperm. From these lighter tints, different varieties show all gradations through yellow or orange to a dark brown, and through pinks and reds to a very deep red. (Plate II, Figs. 1, 2.)

As a rule, the pericarps of all the grains of any one ear, being genetically alike, are alike in color; but this is by no means true of the endosperms of all the grains of the ear. Segregation of hereditary factors preceding the formation of the latter, and the chances for xenia through cross-pollination, make it possible for all the primary colors of endosperm to occur on one ear.

The general uniformity of pericarp color renders an occasional red ear in a white variety a conspicuous object,

and has well fitted it for the unique part that it played in the husking bees of days gone by.[1]

An exception occurs in an occasional red ear with both red and white grains showing various patterns of distribution and having the pigment in the pericarp. The striping of individual grains with red and white also occurs regularly in some varieties. (Plate II, Figs. 3, 4.)

In some varieties the pericarp color, usually red, fails to develop unless the grains are exposed to light during maturity. The "smut nose" variety of flint corn grown in some sections is one of these in which the tip of the ear, protruding beyond the ends of the husks, develops the characteristic color, while the protected portion remains white.[2]

[1] See p. 219, note.

[2] Blakeslee (7) and others have succeeded in printing on such ears photographically, using as the negative a piece of tin foil cut out in simple designs. A portion of the husk is removed from an immature ear and the negative placed over the grains and left there until the ear is mature, the pigment developing in the areas exposed to the light.

CHAPTER XXI

THE ENDOSPERM

In the endosperm of maize, as of all the cereals, lies its chief economic importance. From the standpoint of the miller, the canner, and the feeder, the characteristics and possibilities of this tissue are well understood; and the primary division of the species into agricultural varieties is usually based upon the endosperm. But botanically, also, the endosperm of maize is of extreme importance, being subject to all the uncertainty of interpretation that characterizes the endosperm of angiosperms in general.

Theoretical significance.—Some prefer to consider the endosperm of angiosperms merely a nurse tissue for converting the nucellus into nutriment suitable for the embryo; but such an interpretation does not give due emphasis to the suggestion of sexuality in its origin. The very general participation of one of the sperms of the pollen tube in the formation of the endosperm doubtless has a phylogenetic significance that is overlooked in this purely physiological interpretation. To those who have looked at the problem from the morphological point of view in recent years, the endosperm seems to have a sexual origin, and to be in reality a distinct individual—the embryo's sister-and-a-half. It has a distinct ontogeny, and shows a high degree of differentiation in the adult form. It is peculiar in its triple origin and its consistent failure to have offspring.

No plant surpasses maize in the elaborate differentiation of its endosperm, and many of its characteristics give clear-cut response to genetic experiments. It is not surprising, then, that all recent dissertations on "double fecundation," heredity in the endosperm, or the theoretical significance of the endosperm of angiosperms have centered around this one species.

Early development.—The large nucleus, resulting from the union of the sperm with the two polar nuclei, begins immediately a series of rapid divisions, accompanied by an enlargement of the cavity formerly occupied by the embryo sac. Until fifty or more nuclei have been formed in this way, there is no actual cell division, and the developing endosperm is merely one large, multinucleate cell.

The first walls appear cutting off uninucleate cells at the periphery, free nuclear division continuing meanwhile in the interior. But the one process overtakes the other after a time, and before the endosperm has attained any considerable size, the free-nuclear stage of growth has ceased. From this time onward, growth proceeds both by the enlargement and by the division of cells.

Nuclear divisions.—Very little is known of the cytological details of the growth of the endosperm of angiosperms in general, and a thorough investigation of this point will go a long way toward clearing up the uncertainty as to its meaning. In the growing endosperm of maize, both meitotic and direct divisions of the cells occur. The former prevail in the free-nuclear stage, but the latter, whatever they may mean, are of common occurrence in later development. When meitotic division occurs, there is usually much variation from the

expected triploid number of chromosomes. From this, and from the frequent apparently direct divisions of nuclei, it seems that the exact quantitative division of the chromatin is not so closely guarded here as in ordinary meristematic tissue; and this may afford a partial explanation of some phases of differentiation of the endosperm.[1]

The aleurone layer.—When the endosperm is almost mature, a series of periclinal divisions in the outer cells give rise to the aleurone tissue, a single layer of small, uniform, cubical cells forming a sort of false epidermis. In the aleurone grains located in the cells of this layer is the seat of the series of pigments responsible for the red or blue color of the caryopsis of some varieties.

These aleurone colors offer many problems, for whose solution we must look to the future. They seem to be due to a single pigment existing in two forms and acting as an indicator. Both the red and the blue forms are soluble in either hot or cold water. The red form is acid, and the blue one alkaline.

Advantage is taken of this chemical behavior by some of the Indian tribes of Central America, whose staple crop is a blue variety of corn. Meal made from this variety gives to porridge or other food a disagreeable, dirty-blue appearance not at all appetizing. But some aboriginal student of home economics long ago discovered that the appearance of such food could be materially improved by the addition of lemon juice, which changed the blue to a delicate pink; and this custom is generally practiced in some localities today.

[1] Emerson (54, 56).

The red or blue color of the aleurone may be present in varying shades and in many patterns. In hybrids they often take the form of mosaics for the occurrence of which no thoroughly satisfactory explanation has ever been advanced. (Plate II, Figs. 5, 6.) Other mosaics which are definitely inherited also occur in the aleurone of pure races. Good examples of these are afforded by the "sacred corn" of the Navajos (Plate II, Figs. 7, 8.), each grain of which has a blue or red spot at the tip; and by a variety from the Andes, which seems to practice a type of mimicry.[1]

Chemical and physical nature.—The food stored in the endosperm is chiefly carbohydrate and protein. Traces of fats have been reported, but these have probably been due to errors in the mechanical separation of the endosperm from the embryo before analysis. Deposition of reserve materials begins in the outer cells of the endosperm long before maturity of the seed, and proceeds centripetally. The physical differentiations of the endosperm are determined by the nature and relative amounts of food materials stored in its different parts.

The reserve material of the aleurone is protein, but both proteins and carbohydrates are present in the remainder of the endosperm. In the dent, flint, pop, and soft varieties, the carbohydrate is starch; in the sweet and "waxy" varieties, it consists of starch and various products of the hydrolysis of starch.[2] The

[1] In the districts where this variety is found, the corn is infested with an insect which burrows under the pericarp, and the parasite avoids grains in which others of its kind have already burrowed. By mimicking infested grains by means of its aleurone colors, this variety apparently protects itself from the insect with some effectiveness. See Kempton (95).

[2] In the so-called "waxy" corn, the carbohydrate is in the form of an erythro-dextrin, a substance of rare occurrence as a permanent deposit in plant tissues (160).

protein in this part of the endosperm of all varieties seems to be amorphous, being, in all probability, merely a constituent of the desiccated cytoplasm.

In the parts of the endosperm where the protein or colloidal carbohydrate is sufficiently plentiful to form a matrix filling the spaces between the starch grains, the tissue is hard and translucent; when the amount of colloid is insufficient to fill all these interstices, the endosperm is softer and more or less opaque. (Plate II, Figs. 9, 10.)

In an individual grain, or in a well-defined variety in which the starch grains are uniform in size and shape, the hardness of the endosperm is an accurate index to its protein content; but this test fails in the comparison of widely different varieties. Some very hard, flinty varieties have, in their endosperm, a protein content lower than that of some relatively soft varieties. In the former, the starch grains are large, angular, and closely fitted together, and a small amount of nitrogenous material is sufficient to produce the flinty character; in the latter, the starch grains are small, rounded, and loosely arranged, and even a large amount of protein is not capable of filling all the spaces and producing hardness and translucency.

The yellow pigment of the endosperm seems to be intimately associated with this protein, and the deep-yellow tints are almost always confined to the corneous portions of the endosperm.[1]

Little is known of the chemical nature of this yellow pigment. It is readily soluble in alcohol, and less so

[1] Some authorities report a yellow pigment in the aleurone of varieties that do not have one of the other aleurone pigments; but, if these are present, they are so little different from the colorless condition as to be seen with difficulty.

in several other solvents. Further investigation may explain its constant association with protein by showing it to be the pigment-bearing portion of some conjugate protein.

The real or supposed superiority in the feeding value of yellow varieties of corn, as compared with white varieties, has been explained by the assumption that an important vitamine, similar to that in the carrot, is associated with this yellow pigment;[1] but this is hardly more than a guess at present, and positive evidence to show that there is any consistent difference in nutritive value associated with difference in color is still lacking.

In keeping with the centripetal development of food materials, the dense, flinty portion of the endosperm is localized in definite peripheral regions. It may vary in extent from a very thin layer over all portions of the endosperm not in contact with the embryo, to a mass constituting almost the whole of the endosperm; but in contact with the cotyledon there is always at least a small region of floury endosperm.

As a grain loses moisture at maturity, there is invariably more or less shrinkage; and the floury portion of the endosperm is often disrupted by the appearance of an air-hole. But compensation for shrinkage may also be made by the wrinkling of the surface of the fruit. This, together with other factors, makes the external appearance of the fruit a good index to the physical and chemical nature of the endosperm.

Endosperm varieties.—In the flint, pop, and floury varieties, the corneous portion of the endosperm is in a rather uniform layer over all the other parts except the

[1] Palmer (114).

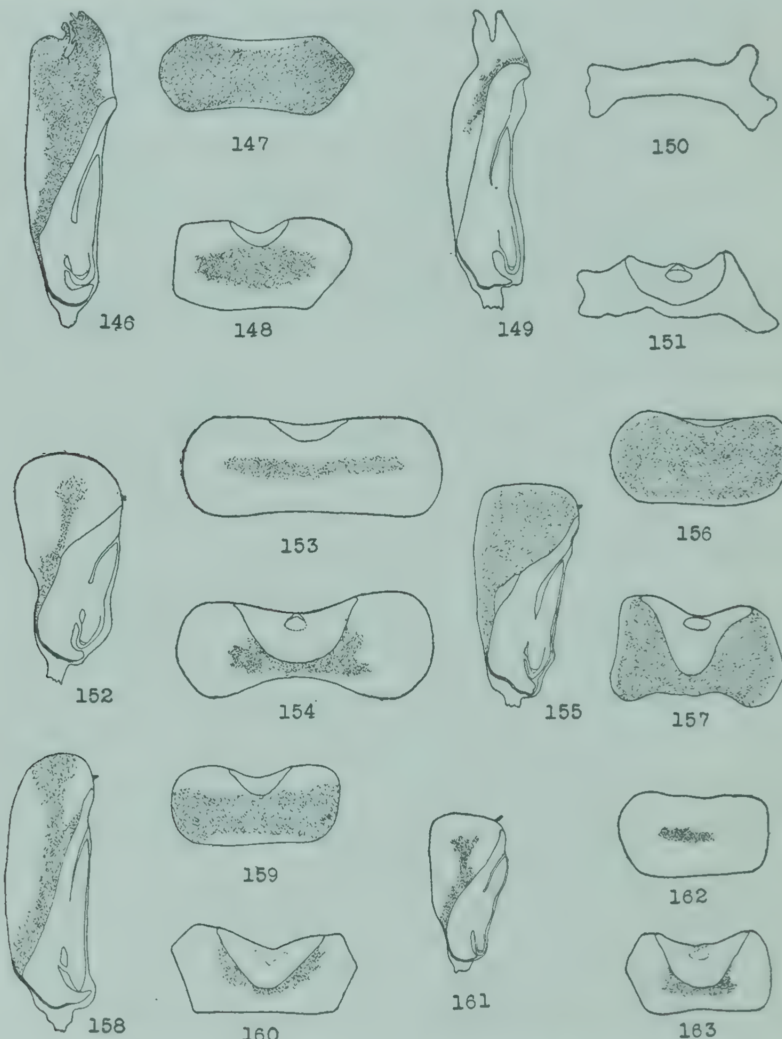
base and that portion in contact with the scutellum. This layer is very thin in the soft varieties, but in pop varieties it may be so thick that only a small region of floury tissue remains. The flints are intermediate between soft and pop varieties. The uniformity of this corneous layer leaves no weak places for wrinkling, and the external contour is not affected by shrinkage. Soft grains may be distinguished from flints and pops by the more translucent appearance of the latter. Flints and pops may readily be distinguished by the diminutive size of the latter, in most cases.

The corneous portion of the endosperm of dent corn is so disposed that it does not cover the top of the grain, and this weak place responds to shrinkage by permitting a pronounced wrinkle or "dent." (These various types of endosperm are shown in Figs. 146–63.)

The peculiar mixture of carbohydrates present in the endosperm of sweet corn is subject to great decrease in size on losing its moisture, and the exterior of the grain, unsupported by anything like the corneous layer, takes on a very characteristic wrinkled appearance (Figs. 149–51, p. 160, and 167, 169, 171, p. 167). When thoroughly dry, the interior mass, made up of misshapen starch grains imbedded in protein and colloidal carbohydrate, assumes a translucent, flinty appearance similar to that of the corneous portion of other varieties.

Sweet corn is apparently the same as other varieties except that it has lost the ability to produce fully developed starch grains. Hybridization of sweet varieties with soft starchy varieties produces grains indicating that sweet corn may be differentiated into soft, flinty, and dent varieties that cannot synthesize starch efficiently.

Just why they cannot do this is not well understood, but, from the corroded appearance of the starch grains that are formed, it seems probable that they may be built up and then partly hydrolyzed, or formed in the presence of a weak hydrolyzing agent.



FIGS. 146–63.—Longitudinal and transverse section of grains of the principal endosperm varieties: Figs. 146–48, dent. Figs. 149–51, sweet. Figs. 152–54, flint. Figs. 155–57, soft. Figs. 158–60, flinty dent. Figs. 161–63, pop. In each diagram the stippled portion indicates the soft, and the unshaded portion the corneous, part of the endosperm.

The "popping" of corn.—One of the peculiar properties of the grain of corn is its ability to "pop" when heated. This is, to a degree, a characteristic of the grains of all varieties of maize, as well as of the seeds of many other grasses; but it is most marked in the small, flinty grains of the common pop corns. The act of popping consists essentially of a miniature explosion, resulting from the slow application of heat to the grain, in which the endosperm suddenly expands, and the grain turns inside out.

This phenomenon has, in the past, been attributed to a number of more or less imaginary factors. It was once supposed that the explosion was due to the expansion of a small volume of air in the floury portion of the endosperm in the middle of the seed; but some of the best popping varieties are the most poorly constructed for this, and the marked changes in the texture of the endosperm indicate that the force causing the explosion is distributed throughout the corneous portion of the endosperm, and not localized in any one part. Until a few years ago, the favored theory seemed to be that the vaporization of a volatile oil caused the disruption; but the endosperm contains little, if any, oil, and seeds that have been treated with ether pop as well as any. Pieces of endosperm pop like whole grains.

A summary of all that is definitely known at present of the popping process (159) indicates that it is due to the expansion of the moisture content of each individual starch grain, after partial hydrolysis during the heating process. The confinement of this pressure for a time, followed by its sudden release, is an important factor, and this is the rôle of the flinty matrix of protein. Flinty

varieties pop best, and floury ones to only a slight degree. Pop corn combines flinty texture with small size of grain and affords the optimum conditions for popping. There is little or no indication that popping is to be attributed to any peculiarity in the minute structure of the starch grain.

The popping process is imitated commercially in the preparation of the "puffed" cereals. Here the grain, containing the proper amount of moisture, is confined in a metal drum, whose temperature is then raised to the point that experiment has shown to be best, when a sudden release of the pressure, brought about by opening the drum, causes all the partially hydrolyzed starch grains to burst simultaneously.

EXPLANATION OF PLATES I AND II

Plate I (see frontispiece)

Colors of the endosperm of maize. All of these colors are often incorporated in a single variety such as some of those grown on Indian reservations in the western part of the United States at the present time.

Plate II

Pigmentation of the caryopsis.

Figs. 1, 2.—Sections through peripheral tissues, showing pericarp (*P*), testa (*T*), aleurone (*A*), and starchy endosperm (*S*). The pericarp may be red or brown, ranging from the darkest shades to others so light that they can scarcely be distinguished from white. The testa is a crushed mass of colorless cells. The aleurone may be red, blue, or white, two or all three of these colors sometimes occurring in the same grain in the form of mosaics. In these mosaics each cell is distinctly one color or the other, as shown in Fig. 2, which is on the boundary line between blue and

PIGMENTATION OF THE [illegible]SIS

varieties pop best, and floury ones to only a slight degree. Pop corn combines flinty texture with small size of grain and affords the optimum conditions for [illegible] is to be attributed to any peculiarity in the minute structure of the starch grain.

[illegible] containing the proper amount of moisture, is confined [illegible] the point that experiment has shown to be best, when a [illegible] the drum, causes all the partially hydrolyzed starch grains to burst simultaneously.

EXPLANATION OF PLATES I AND II

Plate I (see frontispiece)

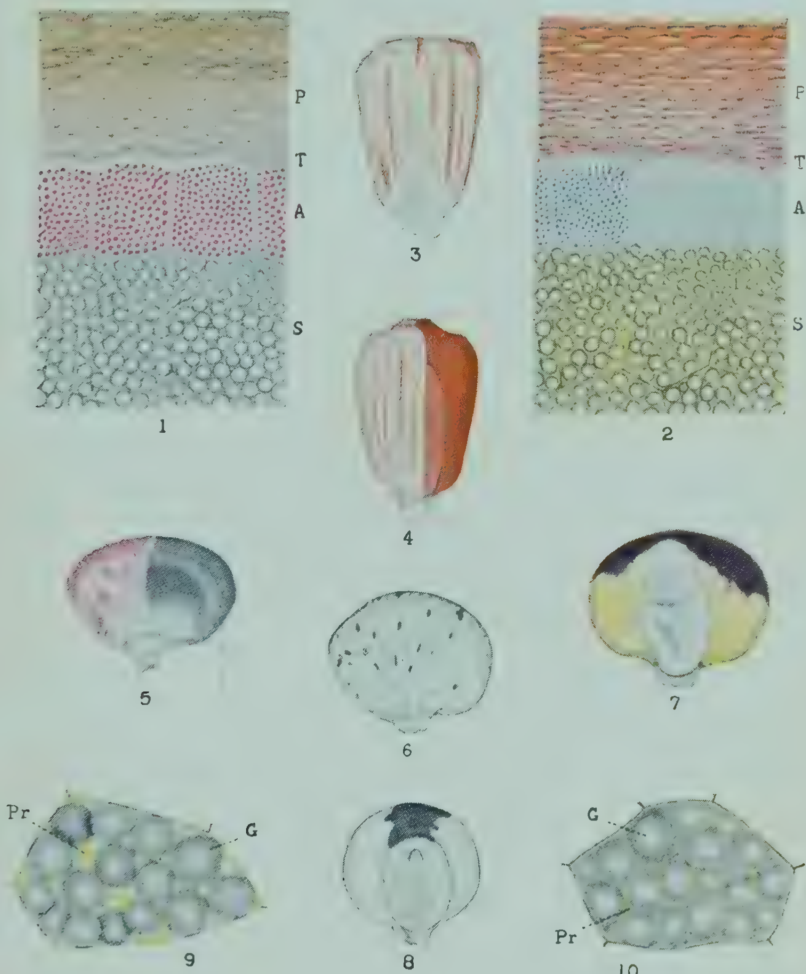
[illegible] on Indian reservations in the western part of the United States at the present time.

Plate II

Pigmentation of the caryopsis.

[illegible] pericarp (*P*), testa (*T*), aleurone (*A*), and starchy endosperm [illegible] The pericarp may be red or brown, ranging from the d[illegible] [illegible] white. The testa is a crushed mass of colorless [illegible] The aleurone may be red, blue, or white, two or all three of [illegible] sometimes occurring in the same grain in the [illegible] In these [illegible] each cell is distinctly one color or [illegible] in fig. [illegible] which is on the boundary line be[illegible]

PLATE II



PIGMENTATION OF THE CARYOPSIS

white in a mosaic. The starchy endosperm may be either yellow or white, depending on the pigmentation of the desiccated protoplasm filling the interstices between the starch grains.

FIGS. 3, 4.—Variegated pericarps. These must not be confused with aleurone mosaics, the seat of pigmentation being entirely different in the two cases.

FIG. 5.—An endosperm *chimera.* The exact cause of this peculiar distribution of pigmentation, where the grain is sharply divided into two parts, is unknown. It is supposed to be due to some anomalous behavior of the chromatin in the early divisions of the primordial nuclei of the endosperm. Grains of this type are to be sharply distinguished from those having variegated pericarp, as in Fig. 4.

FIG. 6.—A typical aleurone mosaic.

FIGS. 7, 8.—The peculiar hereditary aleurone pattern of the Navajo "sacred corn."

FIGS. 9, 10.—Cells from the starchy endosperm of soft and flint corn, respectively. (The cells have been treated with iodine, which turns the starch blue and accentuates the yellow color of the nitrogenous matrix filling the interstices between the starch grains.) The endosperm in Fig. 10 had only 6 per cent protein, but this was sufficient to fill the spaces between the angular starch grains and produce the flinty texture. In Fig. 9, the much higher protein content (12 per cent) was insufficient to produce the flinty effect. Some flinty endosperms having as high as 15 per cent to 17 per cent probably have the rounded starch grains with all the interstices filled with the nitrogenous material.

CHAPTER XXII

PHYSICAL CHARACTER OF THE CARYOPSIS

Many factors combine to determine the general physical nature of a grain of corn. Much of this depends upon the nature of the pericarp itself, but position on the ear and proximity of other grains also play an important part. Inasmuch as the last steps in the process of maturity have to do with the completion of the endosperm, the conditions under which the grains mature are also significant, marked differences in appearance sometimes being produced by hastened maturity due to frost or drought.

Size.—The size of the fully matured grain is usually limited by the pericarp, which is under a high state of tension throughout development. The grains nearest the middle of the ear, having the largest pericarps and being in the best position to utilize their capacity, are generally the largest on the ear. Those at the base are often as large, but they are sometimes forced by pressure of the husks to assume shapes in which they cannot make the best of their limitations; and there is a tendency for the grains toward the tip of the ear to decrease in size as a correlation with the indeterminate nature of the whole inflorescence (Fig. 172).

Grains usually reach their maximum size when they have had opportunity to mature fully on an imperfectly filled ear. This condition not only insures abundant nutrition, but, by relieving pressure on all sides, gives the grain an opportunity to make the most of its pericarp by approximating a spherical shape.

Grains resulting from cross-pollination have been shown to be larger, on the average, than those produced by self-pollination, this being an unusual expression of the increased vigor of a hybrid.

Among different varieties, there is a wide range in the size of the grain. In some very small pop varieties, the average weight of the grain may be as low as .015 grams, while the average grain of some of the largest varieties grown around Cuzco, Peru, may weigh a hundred times as much. Individual grains, representing fluctuating variations, may be selected to show an extreme range in size much greater than this.

The smallest grains are to be found in the pop varieties, but certain soft varieties are known whose seeds are much smaller than those of some pop varieties. The heaviest grains probably occur in the soft varieties from Cuzco, and the difference in volume between these and their diminutive relatives in the pop varieties is more marked than their difference in weight, because of the greater density of the corneous endosperm of the latter.

Shape.—The true shape of a grain of corn, as determined by its pericarp, is brought out only when the grain is permitted to develop in isolation, as on a poorly filled ear, or in a paniculate inflorescence. Under such conditions, two distinct types of grain may occur: a rounded one, tending to be almost spherical, and a conical one with a sharp apex at the point of attachment of the silk. In either form, the embryo, seeking to assume its characteristic shape, may disturb the symmetry of the whole grain. The form with the rounded apex is by far the most common, the conical shape

occurring most commonly in the "rice" or "rat-tooth" varieties of pop corn.

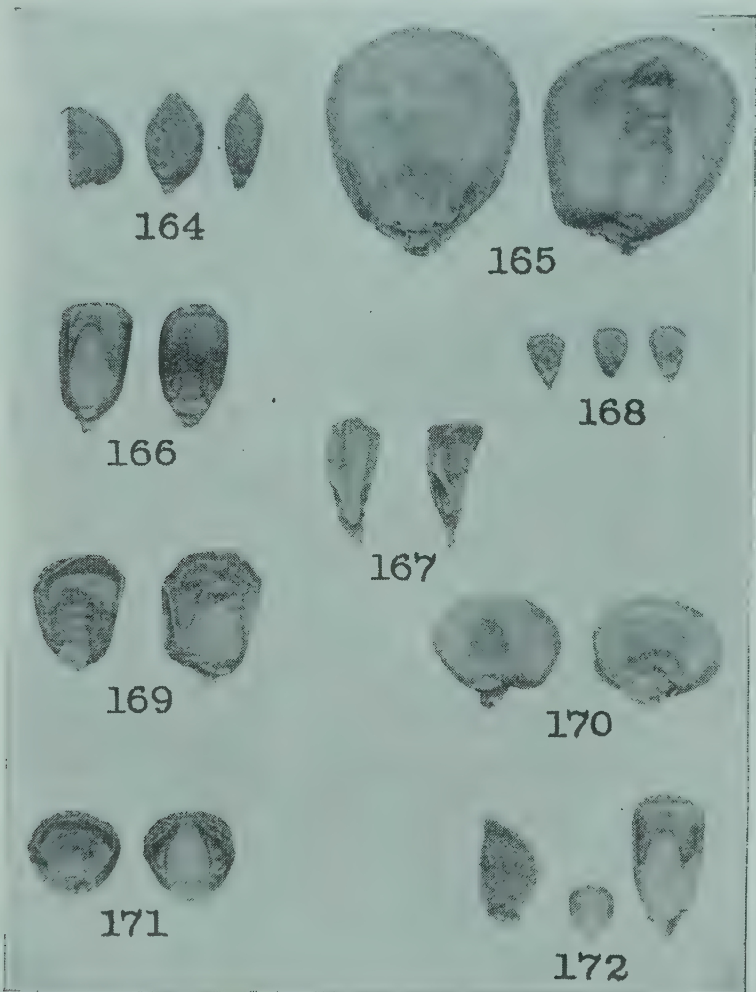
But when a grain develops in a well-filled ear, it is subject to compression in two directions, and the result is a longer and more slender grain. When an ear has eight rows or fewer, a pressure is exerted on each grain only by other grains in the same row; and, meeting with no resistance in expanding tangentially, the grain becomes broad and flat (Figs. 165, 169, 170). When there are more rows on the ear, the influence of lateral pressure on the grain is felt, and it assumes a trapezoidal, or almost rectangular, shape.

The long, slender grains of "shoe-peg" dent varieties are produced on ears having a large number of rows. The peculiar long, irregular grains of Country Gentleman sweet corn (Fig. 167), and a few other varieties, are the result of unusual crowding, due to a structural peculiarity already discussed.[1] Each pistillate spikelet produces two grains instead of one, and the pressure of the developing grains is so great as to eliminate all semblance of rows and all geometrical regularity in the shape of the grain.

At the base of the ear the pressure of the husks causes a few grains to be short, rounded, and asymmetric. At the tip, the absence of any restricting influence permits the grains to take on the rounded form determined by the pericarp. The anomalous compound, or fasciated grain, that has occasionally been observed[2] has the appearance of a grain bearing an embryo on each side. Structurally, it is due to the fusion, during ontogeny, of two grains by their dorsal surfaces. The possibility of this occurrence is suggested by the proximity of the two

[1] See pp. 118, 119. [2] Wolfe (170).

grains in a spikelet of Country Gentleman sweet corn, and by steps in development where the primordium of the two florets of the spikelets should divide. The failure of this division to take place results in the compound structure.



FIGS. 164–72.—Some types of grain: Fig. 164, rice, or squirrel-tooth pop corn. Fig. 165, the giant Cuzco corn, from Peru. Fig. 166, a well-bred dent corn. Fig. 167, shoe-peg grains of Country Gentleman sweet corn. Fig. 168, very small grains of a pop variety. Figs. 169, 171, types of ordinary sweet corn. Fig. 170, an eight-rowed flint variety. Fig. 172, grains from base, tip, and middle of an ear of dent corn.

Color.—The color of the grain, as a whole, is an optical blend of all the visible layers of color. The corneous endosperm, the aleurone, and the pericarp have their own uncorrelated color potentialities, and the latter two are usually more or less transparent, allowing more deeply seated colors to show through. As a result of these conditions, the pure blues and reds of the aleurone may be blended with the yellow of the corneous portion, and any one, or a combination of these, may in turn be overlaid with one of the innumerable shades and tints of the pericarp.[1]

[1] Correns (40), p. 36, tabulates the possible combinations of all these pigments located in the different parts of the caryopsis and describes the resulting color effects.

CHAPTER XXIII

HEREDITY

The biological researches of the first quarter of the twentieth century have centered chiefly about the enigma of heredity; and no general treatise on maize would do justice if it did not discuss, to some degree, the special aid that this plant has given the botanist in his attempts to read this world-old riddle.

The first tangible step toward the modern genetics was made by Gregor Mendel, an Austrian monk, more than half a century ago. How his work remained in obscurity for a generation is an old story. But it is not so generally known that the maize plant was the vehicle by which both Correns and De Vries later developed the same fundamental principles of heredity by contemporary researches, rendered none the less brilliant by the discovery of Mendel's undisputed claim to priority. And neither is it generally known that, in keeping with the eternal fitness of things, the credit for first bringing this American plant into the light seriously in the cause of genetics belongs not to Holland nor to Germany, but to America, for McCluer's (106) early experiments with maize established the facts, if not the generalizations, of Mendelism, although his published results, like those of Mendel, were too premature to receive merited appreciation.

But maize has not made its sole contribution to our knowledge of heredity by supplying material for pioneers in the field. Many principles of more recent discovery

have also come to light or been substantiated through its behavior. As has been stated in other connections, it is an extremely variable plant; and its varieties hybridize readily. Many of the studies that have been made on the heredity of its vegetative aspects have been of a routine nature, resulting in a tabulation of characteristics as dominant or recessive, or orthodox or exceptional, in behavior; but for the general reader these have a limited interest.

The phenomenon known as *xenia*, made possible by the variability of the endosperm, enables the investigator to secure certain genetic results with maize in fewer generations than with almost any other plant. The triparental origin of the endosperm also affords opportunity to test the effect of a hereditary factor as opposed to the double application of its opposite, thus throwing light upon the mechanism of multiple factors. In its immediate and striking response to self-pollination, maize is almost without an equal, and this gives it a prominent place in all studies of the effect of inbreeding.

Xenia.—In the course of ordinary experiments in the hybridization of plants, two generations must be grown before a perceptible result is obtained, and three are necessary for the production of a characteristic Mendelian ratio. The first generation affords material for the cross, but the visible characteristic of the hybrid seeds are usually determined wholly by the maternal parent. In the generation of plants grown from these seeds, the dominance of some characteristics becomes apparent. Self-pollination of these individuals of the second generation, crossing them *inter se*, or back-crossing them with

pure recessives, gives seeds which will, in the next generation, develop into plants whose characteristics satisfy certain theoretical ratios.

Advantage being taken of the peculiarities of the endosperm, the same results may be secured one generation sooner with maize. When sweet corn is pollenized with a starchy variety, the embryos of the seeds are unaffected visibly, although certainly hybrids; but the influence of the hybridization is at once apparent in the endosperms, which are starchy in character. Self-pollination of a plant grown from one of these seeds produces sweet and starchy seeds in the monohybrid ratio (3 starchy: 1 sweet).[1]

To this immediate effect of cross-pollination has been given the name "xenia,"[2] the term signifying "a gift of hospitality." Although loosely defined at first, the term is now applicable, in a strict sense, only to the immediate effect that may be produced *in the endosperm* of a plant by cross-pollination. It finds its best expression in maize, but it is known to occur in a few other plants.[3]

Xenia was regarded as a curiosity almost as soon as the white man came into contact with maize, and how long the Indians had been familiar with it before that we do not know. The varieties that they cultivated exhibited a far wider array of colors and endosperm

[1] Grains, intermediate in character, sometimes complicate this ratio, but the rarity of such occurrence justifies the use of these well-known varieties in explaining the principle of simple Mendelian ratios. The writer has given elsewhere (160) a possible explanation of the occurrence of these intermediate forms.

[2] Focke (63).

[3] Xenia has been reported in hybrids between varieties of rice, between wheat and rye, and between maize and teosinté.

types than is ordinarily seen today, and the conditions for the occurrence of xenia must have been good at times. We are told on good authority that the Indians did observe it and attributed it to the mingling underground of the roots of different varieties. But, as early as 1724, we find an ingenious New England naturalist (46) applying conclusive tests to this theory and finding it inadequate.[1] He believes that the mixture that occurs must be brought

[1] *Philosophical Transactions* (VII, 57–59) gives an abstract of this communication. The following is a part of the abstract pertaining to maize:

"The Indian corn is of several colours, as blue, white, red, and yellow; and if they are planted separately, or by themselves, so that no other sort be near them, they will keep their own colour. . . . . But if in the same field you plant the blue corn in one row of hills, as they are called, and the white or yellow in the next row, they will mix and interchange their colours; that is, some of the ears of corn in the blue corn rows, will be white, or yellow; and some again, in the white or yellow rows, will be of a blue colour . . . . this mixing and interchanging of colours has been observed, when the distance between the rows of hills, has been several yards; and Mr. D. has been assured, that the blue corn has thus communicated, or exchanged, even at the distance of 4 or 5 rods; and particularly in one place, where there was a broad ditch of water between them. Some of our people, but especially the aborigines, have been of opinion, that this commixtion, and interchange, was owing to the roots, and small fibers reaching to and communicating with one another; but this must certainly be a mistake, considering the great distance of the communication, especially at some times, and cross a canal of water; for the smallest fibers of the roots of Indian corn cannot extend above 4 or 5 feet. Mr. D. is therefore of opinion that the stamina, or principles of this wonderful copulation, or mixing of colours, are carried through the air by the wind; and that the time or season of it is when the corn is in the earing, and while the milk is in the grain for at that time, the corn is in a sort of estuation, and emits a strong scent. One thing which confirms the air's being the medium of this communication of colours in the corn, is an observation, that a close, high board fence, between two fields of corn that were of a different colour, entirely prevented any mixture or alteration of colour, from that they were planted near."

about in some way by something carried by the wind; and his theory is correct as far as it goes, although not fully substantiated and explained until nearly two hundred years later.

Near the close of the century just past, the discovery of "double fecundation" in angiosperms gave promise of a cytological explanation of xenia, and new interest was awakened in the experimental study of the phenomenon. The repeated demonstration of the behavior of the sperms of maize in fecundation has since established the fact that the pollen tube makes a contribution to the constitution of the endosperm as well as to that of the embryo, and that a hybrid embryo is necessarily accompanied by a hybrid endosperm.[1] This explains, beyond any reasonable doubt, the mechanism of xenia; and the transmission of hereditary characters to the endosperm of maize is one of the strongest evidences that we have of the sexual nature of the nuclear fusion in which the endosperm originates.

The experimental work done on maize in the past two decades indicates that xenia may be expected to occur: (1) when the female parent bears the recessive, and the male the dominant, of a pair of endosperm factors, neither being accompanied by an inhibiting factor for the dominant; (2) when the female parent bears a dominant endosperm factor, or combination of factors, whose action is capable of being inhibited by a factor carried by the male; or (3) when the male and female parents, respectively, bear latent complementary factors whose interaction is necessary for the production of a definite effect in the endosperm.

[1] See (70), (109), (154).

Multiple factors.—The multiple factor hypothesis seeks to explain certain cases in heredity where a single visible characteristic seems to be due to two or more factors, any one of which is capable of producing the same qualitative effect. The key to the whole problem lies in a question as to whether two factors for the same characteristic are really any more potent than a single factor; and for this question the endosperm of maize is ready with an answer.

In flint and soft corn, we have two types of endosperm whose genetic behavior is of unusual interest. In reciprocal crosses between these two varieties, the endosperm produced always has the physical character of that of the female parent. That this unusual behavior is not due to the failure of the sperm to unite with the endosperm nucleus is shown by selecting as the female parent in each cross a white variety, and for the male parent a yellow one. The occurrence of xenia, in each case, with respect to color indicates that the origin of the endosperm is normal.

The cytological fact that the female parent contributes two-thirds, and the male one-third, of the hereditary material entering into the organization of the endosperm offers the explanation that two applications of a factor may form a combination more potent than one application of the opposite factor. Conventional treatment in succeeding generations gives results in accord with this hypothesis.

If the difference between the flinty and soft endosperms is due to a single factor or a closely linked group of factors, the relation between the opposite allelomorphs is probably that of incomplete dominance; and a blend

would be secured if an endosperm could be produced by the union of equal parts of the two kinds of hereditary material. But double fecundation makes this impossible. This raises also the old question as to whether a pair of opposite allelomorphs showing incomplete dominance may really be interpreted on the presence-and-absence basis. It is easy to see how absence might dilute presence, producing an intermediate condition, but how a further application of absence could completely eliminate presence is more difficult to comprehend.

The histological and chemical properties of the endosperm indicate, however, that the flinty or soft character is probably very much more complex than the experimental work done thus far would indicate. There are doubtless many kinds of flints and many kinds of softs, physical textures apparently alike being due to widely different sets of hereditary and environmental factors, and only a better knowledge of the physical basis of the hereditary phenomena can clear up this point.

The experimental data, together with the theoretical explanation, may be seen from the following summary:

1. A pure flint pollenized with a pure soft gives flinty grains; in the reciprocal cross, soft grains are produced (Table I).

TABLE I

Female		Male		Embryo		Endosperm	
FF	×	SS	=	FS	+	FFS	(flinty)
SS	×	FF	=	SF	+	SSF	(soft)

2. Self-pollination of either of these hybrids, or back-crossing with either parent-type, produces flinty and soft grains in equal numbers (Table II).

TABLE II

Female		Male		Embryo		Endosperm	
FS	×	FS	=	FF	+	FFF	(flinty)
				FS	+	FFS	(flinty)
				SF	+	SSF	(soft)
				SS	+	SSS	(soft)
FS	×	FF	=	FF	+	FFF	(flinty)
				SF	+	SSF	(soft)
FS	×	SS	=	FS	+	FFS	(flinty)
				SS	+	SSS	(soft)

3. A white flint, pollenized with yellow soft, gives yellow flinty grains; a white soft, pollenized with yellow flint, gives yellow soft grains (Table III).

TABLE III

Female		Male		Embryo		Endosperm	
FFWW	×	SSYY	=	FSWY	+	FFSWWY	(yellow flinty)
SSWW	×	FFYY	=	SFWY	+	SSFWWY	(yellow soft)

4. Self-pollination of either of these latter hybrids gives flinty and soft grains in equal numbers, and yellow and white in the ratio 3:1. The whole population falls into four phenotypes, as follows: 6 yellow flint, 6 yellow soft, 2 white flint, 2 white soft (Table IV).

Hybrid vigor.—The popular notion that inbreeding is conducive to degeneracy, and cross-breeding toward increased vigor, is as old as the practice of breeding itself; and the mechanism of this behavior has been sought in many researches. Maize is especially responsive to this treatment, and has held a prominent place in recent investigations.

A single generation of self-pollination in this plant usually causes a marked decrease in vigor; and con-

tinued inbreeding results in still further weakened plants, some of which may be characterized by complete or partial sterility, dwarfing, androgyny, albinism, or susceptibility to disease. But, after five or six consecutive generations of this treatment, there comes a time

TABLE IV

Female		Male		Embryo		Endosperm		
WYFS	×	WYFS	=	YYFF	+	YYYFFF	flinty	yellow
				YYFS	+	YYYFFS	flinty	yellow
				YWFF	+	YYWFFF	flinty	yellow
				WYFF	+	WWYFFF	flinty	yellow
				YWFS	+	YYWFFS	flinty	yellow
				WYFS	+	WWYFFS	flinty	yellow
				YYSF	+	YYYSSF	soft	yellow
				YYSS	+	YYYSSS	soft	yellow
				YWSS	+	YYWSSS	soft	yellow
				WYSS	+	WWYSSS	soft	yellow
				YWSF	+	YYWSSF	soft	yellow
				WYSF	+	WWYSSF	soft	yellow
				WWFF	+	WWWFFF	flinty	white
				WWFS	+	WWWFFS	flinty	white
				WWSF	+	WWWSSF	soft	white
				WWSS	+	WWWSSS	soft	white

when inbreeding has no further effect, and the races that have survived show, in their respective populations, a striking uniformity seldom seen under normal conditions. Some of the abnormal races may survive to this end, but the lethal nature of the anomaly insures the extinction of many of them.

Hybridization of two of these weakened races which show no anomalies usually produces a strong, vigorous strain. The same improvement is noted when two

widely separated agricultural varieties of maize are crossed. In general, the more different two varieties are, or the more widely separated their habitats, the more marked is this response to hybridization.

These experiments indicate that in an ordinary variety of maize, whose plants are accustomed to cross-pollination among themselves, but protected from hybridization with widely different varieties, there is a degree of heterozygosis that can be increased by crossing with other varieties, or reduced practically to homozygosis by inbreeding.

The anomalies brought to light by inbreeding are, for the most part, recessive characteristics visible only in homozygous individuals. But why should vigor be such a faithful index to the degree of heterozygosis?

One explanation of this peculiarity is, that, between the two factors of an allelomorphic pair, there is an indefinable physiological interaction more conducive to vigor when the dominant and recessive are paired than when the two dominants or the two recessives occur together. The general vigor of the plant would depend, then, upon the number of pairs of contrasting factors that took part in its development. Inasmuch as this physiological interaction between allelomorphs is purely hypothetical and has never been demonstrated experimentally, this theory suggests a point of attack but does not really solve the problem.

Another theory employs the machinery of modern genetics. Characteristics conducive to vigorous development are usually dominant, and the general vigor of the plant may depend upon the number of dominant characters that it possesses. Inbreeding a hetero-

zygous individual produces less vigorous offspring because it gives rise to separate strains, each of which has only a part of the dominant characters of the parent-stock. Crossing two varieties produces a race more vigorous than either parent, because it has all the dominant characters of both parents.

If this be the principle concerned, it would seem that races ought to be secured, which, being homozygous for a large number of characters, would retain their vigor in spite of inbreeding; and that others, homozygous for a large number of recessives, would show no increase in vigor on being hybridized. Races tending in these directions are sometimes found, but the mathematical possibility of such occurrences is slight, and it is further complicated by linkage.

Neither of the theories here outlined hopes to say the last word on the question of hybrid vigor in plants and animals in general, and factors at present unknown, or not seriously considered, may play important parts in the complete explanation to come in the future. The environmental conditions under which the evolution of the maize plant has taken place will especially be given more emphasis in future considerations; for the floral structure of the plant and the agricultural practice of ages have constituted a condition conducive to cross-pollination, and the present genetic behavior may be capable of explanation in terms of adaptation.

Non-Mendelian views.—Although the hereditary phenomena here described afford rare and striking substantiations of some of the extreme applications of modern Mendelism, it is only fair to state that a number of careful investigators question the accuracy of some of

these observations, or derive from them very different interpretations. Up to the present, these views have been iconoclastic rather than constructive, and none have offered any serious competition with Mendelism in the eyes of the botanical public. But these dissenting opinions have a decided value and must not be disregarded, even though some of them strike at the very heart of Mendelism.

Only the future can tell whether or not the modern structure of genetics can stand the test. Investigations will continue, and fragments of fact must come to light; and, as time goes on, it may come to pass that this plant, which has done so much to develop the modern science of genetics, will prove an agent to break theories as well as make them; and it is safe to predict that if Mendelism itself, or its ornate embellishments of these later days, shall ever crumble to dust, these same problematical structures of the maize plant will be present and making their contribution toward the revelation of truth.

CHAPTER XXIV

BREEDING

Intelligent methods of breeding will probably give greater returns from maize than from any other cereal. The variability of the plant, under ordinary agricultural conditions, makes a rigid selection essential to the maintenance of any approximate standard of excellence, and, at the same time, affords a standing promise of improvement. Only a small amount of seed is necessary for planting an extensive area, and the seeds are aggregated in large units. These conditions reduce to a minimum the task of seed selection. The monoecious nature of the inflorescence renders hybridization easy of performance, opening all the possibilities of securing new combinations of characters and the increased vigor of hybrids.

Because of the benefits to be derived from it, maize breeding has been practiced for a very long time. One of the important responsibilities of the medicine man of the aboriginal community was to direct the selection and care of the seed corn. The white man slowly learned that he, too, must maintain the standard of his crop by breeding. The comparative ease with which the crop could be grown at first eliminated the spur of necessity, and the Indian's persistent mingling of the intangible and mystic of his religion with the concrete practices of his daily life made him a poor teacher; and it remained for almost the closing years of the past century to convince civilized man of the necessity of scientific corn breeding and to teach him its fundamentals.

Methods.—From crude beginnings corn breeding has grown to be an elaborate art. The indefinite aim of producing merely more corn has given way to an attempt to reach definite ideals of perfection coincident with high yields. Many methods have been employed in the attainment of these results, with an increasing use in recent years of the principles of genetics.

Maize is readily susceptible to the improving influence of both hybridization and selection. To the latter of these, we are indebted for most of the progress of the past; but recent experimental work indicates that we may be now entering a new phase of the work, in which hybridization is to assume a more important rôle.

Selection.—The selective improvement of corn doubtless had its beginning in the almost unconscious choice at planting time of the best ears from the depleted store left from the previous year's crop. Inefficient as was this method, it is far too extensively employed in many parts of America even to the present day. Foresight on the part of the more intelligent farmers led long ago, however, to an earlier and earlier selection of seed until the initial choice came to be made in the field at, or before, harvest time. This practice not only gives a wider field for selection, but also makes possible the consideration of many fundamentally important qualities not exhibited in the ear alone.

Some of the most successful breeders of today plant each year in a special plat, at considerable distance from any other corn, the few best ears available. From this plat are rigidly selected the few ears to be used in a similar planting the next year, the bulk of this élite class being used as seed for the main crop.

As a check on the marked variation in yield of the offspring of different ears, the "ear-to-row" test has been devised. In the breeding plat, a single row is planted from each ear entering into the test; the yields of the different rows are found at harvest time, and seed for the next crop is selected from the row showing the best yield.

Hybridization.—In general, hybridization offers opportunity for improvement in at least three ways: (1) through the combination in one individual of the good qualities of two or more; (2) through the interaction of latent factors to develop desirable new characteristics; and (3) through an increase in vigor. Attempts to combine desirable characteristics in maize have met with a degree of success, but it is in the production of hybrid vigor that most has been accomplished.

Technique of hybridization.—Few plants are easier to hybridize than maize. The wide separation of the pistillate and staminate inflorescence makes emasculation unnecessary or easily accomplished. The pistillate inflorescence must be covered with a paper bag or some other protective device before the silks appear. Pollen is collected in paper bags tied over the tassels a few days before the pollination is to be made. The only care needed is to make sure that the protection is adequate, in each case, and to avoid contamination with stray pollen grains at the time of actual pollination. The pollen grain has a short period of viability, and pollen-carrying insects seldom cause difficulty.

When hybrid vigor is the only thing sought, a field method of hybridization on a larger scale is employed. Alternate rows in the breeding plat are planted from

one ear or a few ears of one variety, and the other rows with a different variety. By proper selection of the two stocks, or by planting at different times, the two varieties are brought to flowering at the same time. Before any pollen has been shed, all the plants of one variety are detasseled, and, at harvest time, the seed is selected from these rows. The prompt and decisive results of this procedure are giving the method an extensive use in practical agriculture.

Pedigree breeding.—In the application of the principles already described, the breeder is unable to control at any time the male parent of the plant except by hand pollination, and this renders impossible the maintenance of pedigreed seed in sufficient quantity for practical use. Consequently, a true breeding, uniformly good population cannot be expected; a high average of quality and yield is all that can be hoped for, and continued selection is necessary for the maintenance of even this. But, by first taking advantage of inbreeding, even at the sacrifice of vigor, it should be possible in time to produce a variety breeding true for a combination of desirable characteristics.

To attain this end, a number of pure lines are secured by inbreeding a highly selected variety for several generations. Undesirable characteristics are eliminated as they occur, and only the best strains are retained. When homozygosis has been practically reached in a number of strains as indicated by the uniformity of consecutive generations, the lost vigor is regained by blending the best of these strains in a hybrid, and the result should be a variety of limited variability and a high degree of excellence.

The maintenance of such a pedigreed strain requires only that it be propagated under conditions that will prevent its contamination. At present, the only way of securing this is by maintaining a breeding plat at a distance of at least a quarter of a mile from other varieties, and preferably protected on the windward side by woods, orchards, farm buildings, or other windbreak.

Co-operative breeding.—In a work of this kind, there is excellent opportunity for neighborhood co-operation. No one ought to object to growing exclusively a distinctly superior variety for his main crop, and such sweet corn or pop corn as might be desirable could be planted at such times or in such places as not to be a menace. Before such co-operation can be secured, however, the usual barriers of selfishness, ignorance, and prejudice must be broken down. The botanical nature of the maize plant and the fundamentals of genetics must be better understood by the farmer; and there must be developed such pride in the possession of thoroughbred plants that the farmer who persists in maintaining a source of contamination in the form of a field of inferior corn will suffer the same contempt as the owner of breachy, scrub live stock used for breeding purposes.

CHAPTER XXV

PRODUCTS AND USES

In an economic way, maize is the most versatile and one of the most dependable of the corn plants. The size and characteristic physical and chemical properties of the plant enable it to fill a wide range of human needs; and it has become so thoroughly interwoven into the life of modern nations that no resource could take its place without an economic revolution. In yield per acre, and in the certainty with which it produces a good crop under widely varying conditions, it is unequaled by any other cereal. Some of its uses are so common as to require scarcely more than passing mention; but others, which utilize properties ordinarily little known, or which are of importance only in restricted localities, demand a more thorough treatment.

The grain is the storehouse of the greater part of the useful material present in the mature plant. It so far surpasses the remainder of the plant in this respect that it is often the only part efficiently harvested, and it is usually made the sole basis for estimating the value of the crop. But, as the necessity for conservation increases, the food value of the stem and leaves is receiving more general recognition; and many unique uses of all parts of the plant have now a permanent place in the arts and industries.

Food for live stock.—The commonest use of corn is for feeding live stock, and much of the grain produced is thus employed without any preparation further than

husking. For cattle the ears are usually broken or chopped into small pieces because of this ruminant's inability to shell the grain from the cob. Whole or broken ears are sometimes fed to poultry, giving the fowls both food and exercise. The shelled grain may be fed to any kind of stock that can eat it in the ear form, and many kinds of stock can be encouraged to eat more and masticate it better when it is shelled.

Soaking or cooking the whole grain is widely practiced, and the increase in palatability and digestibility is thought to make the treatment profitable in most cases. Corn meal in varying degrees of fineness is often used alone, or as a constituent of mixed feeds. This may be made from the grain, the whole ear, or the cobs, the latter having a greater food value than is generally recognized. Many by-products of manufacturing processes are also made into feed for stock.

The grain of corn has insufficient protein to make a balanced ration, the deficiency being in the kind of proteins present as much as in the total protein. As a rule, about half the total protein of a grain of corn is zeïn, and it lacks certain of the amino acids necessary for complete nutrition. Cottonseed meal, tankage, or leguminous plants are usually employed to balance the ration of which corn is the basis.

The nutritive value of the leaves and green stems has long been recognized, and the use of these parts, in the form of fodder or ensilage, is well known. Chemical analyses show that the dry stems, roots, and cobs contain considerable amounts of proteins and carbohydrates; but there is to be expected an appreciable discrepancy between actual content, as shown by chemi-

cal analysis, and practical values, as shown by feeding tests. In spite of popular opinion to the contrary, neither analysis nor feeding test show any consistent difference in food value between white and yellow corn.

The value of corn as a food can best be realized in terms of live stock produced or supported. It produces practically all the pork of America, supplemented, of course, by the nitrogenous foods necessary for a balanced ration; it is fed, at least for several weeks, in the finishing process to millions of cattle being fattened for beef; and it supports, in part, countless numbers of work animals on the farms of America throughout the year.

Milling.—The highly specialized structure of the grain of corn has led to the development of an interesting group of milling and other manufacturing processes.

In earlier days, corn meal was almost universally made by grinding the grain between stone burrs, and mills of this kind are still in use, but they have largely given way to improved types. The texture of the product depends upon both the process and the variety of corn used. Flinty varieties tend to make a coarse, granular meal, while that made from soft varieties is usually finer and floury.

Whole meal is nutritious and palatable, but the bran is sometimes objectionable, and the oil from the embryos of the grains seriously impairs keeping qualities. The one objection is avoided by bolting, and the other by crushing the grains coarsely and removing the embryos before grinding.

The coarsely crushed endosperms, after the removal of the hulls and embryos, may also be screened to

standardize the size of the particles and placed on the market as flake hominy. Hominy grits is only a more finely divided product made in the same way. Both of these products consist largely of the flinty portion of the grain. The soft portion is crushed so readily that it passes through the grading screens and becomes a source of meal or of corn flour.

Lye hominy.—One of the oldest methods of preparing corn for food was discovered by the Indians and is still extensively used. When the grain is cooked with a small amount of an alkali, such as soda, lime, or ashes, the hulls are loosened and partly dissolved until they can be washed off, and the resulting product is lye hominy.

Manufactured products.—Large, well-equipped factories attain a high degree of efficiency in separating the grain of maize into its constituent parts preliminary to the manufacture of its various products. Although they differ in details, all of these follow the same general procedure.

The grain is first steeped in water for a day or two to loosen from one another the hull, the endosperm, and the embryo. After a coarse crushing, for which the machinery is so adjusted as not to break the embryos, the whole mass passes into a separatory receptacle filled with water. Here the oily embryos float, the hulls sink, and the endosperm largely remains in suspension. The starch and protein of the latter are separated by sedimentation and by differences in solubility. The separated solids of the grain are dried, and the proteins in solution in the water used in the process are recovered by evaporation to dryness. When subjected to pressure, the embryos yield crude corn oil. The oil cake, the

hulls, and the crude proteins enter into the make-up of stock feeds.

Corn oil.—In utilizing corn oil, the manufacturer takes his cue from the refiner of cottonseed oil, the two offering much the same possibilities. The purified oil has an agreeable taste, odor, and color, and is, in every way, the equal of olive oil for culinary purposes. When hydrogenated, it is an excellent substitute for lard. A vulcanizing process converts a gum associated with the crude oil into a substitute for rubber, and large quantities of the oil are also used in the manufacture of soaps, glycerine, liniments, dyes, paints, varnishes, and oil cloth.

Starch.—Commercial starches are prepared directly from the amylaceous product of the initial separation of the grain. Besides the ordinary use of starch in the kitchen and in the laundry, there are many others not so well known. It is employed as an adhesive and as a size for cloth and paper; and it forms the body of some kinds of cosmetics, soaps, and candies.

On being hydrolized, starch produces first a series of dextrins and then sugars, the ultimate product being glucose. Each of these has numerous uses. This conversion of starch is accomplished by roasting or by heating it with water and a minute quantity of hydrochloric acid.

The dextrins are used as a size for cloth and paper, as an adhesive,[1] and as a glaze for rice and for coffee.

Sugar.—Crystalline corn sugar is used chiefly as a substitute or adulterant for cane sugar. Consisting of almost pure glucose, it is much less sweet than cane

[1] The so-called "library paste" is largely dextrin.

sugar, but it has equal preserving properties, and is the most easily assimilated of all the sugars. As a food, it is the best of sugars, but, as a flavor, it is surpassed by some others. It may well be mixed with cane sugar for purposes requiring a syrup so thick that cane sugar alone makes it sweeter than necessary.

Syrup.—Commercial corn syrup is a product of the incomplete hydrolysis of corn starch. It is a thick solution of a mixture of glucose and dextrins. It is extensively used as a food and is also employed in the manufacture of leather, chewing tobacco, extracts, caramel, soaps, sponges, and hair tonics.

Varieties used in manufacture.—The yield and quality of corn products is determined in a large measure by the variety of grain used. For hominy and grits the flinty varieties are best, but for corn flour the soft varieties give greater yields. Meal and the products of the more elaborate manufacturing processes may be made from any kind of corn, but some give much better results than others. Because of the cosmopolitan nature of dent corn and its ability to give high yields per acre, it is more extensively used than any other variety in these processes.

Both yellow and white varieties are used for meal, every locality having a decided preference for one or the other; but for hominy and the starch products, white corn is almost universally used.

Because of the marked variation in the physical and chemical properties of the grain, the breeding of more palatable varieties, and of varieties richer in some particular constituent, offers a wide and profitable field for future work. The progress that has already

been made in breeding for increased or decreased oil and protein content suggests the possibilities in this direction.

Sweet corn.—The principal use of sweet corn is for human food. It is harvested as soon as the grains have attained their full size but before much carbohydrate has been deposited in them in the form of starch. It is imperative that the green corn be cooked as soon as possible after removal from the stalk; otherwise, enzymatic activity in the grain continues to change the sugars and dextrins into starch, seriously impairing the palatability. While the ear is still attached to the plant this change is continually taking place; but, under favorable weather conditions, a new supply of sugar is constantly coming into the ear from the leaves, so that there is usually present enough of the soluble carbohydrate to give the grain the desired flavor.

Much benefit can be derived also from an observance of the reversible behavior of the enzyme concerned in the conversion of the carbohydrates in the grain. It seems that the enzyme that changes the soluble carbohydrate into starch also changes starch into the soluble forms, the direction of the reaction being determined by environmental conditions, chiefly temperature. Since low temperatures are conducive to the formation of the sugars, and high temperatures to the formation of starch, it is evident that the sweet corn that must be stored should be kept at low temperatures.

After removal of the husks and silks, the ears are usually roasted or boiled; or the grain may be cut from the cob and prepared in any one of many ways. Corn in the "roasting ear" stage is kept for use out of season by canning or drying.

Pop corn.—A much wider use than is generally realized is given the small varieties of corn that "pop" when heated. Popped corn, treated with butter, salt, sugar, or other flavors, is an important ware of the street vendor. Meal made from the popped grains has many untried possibilities in the manufacture of cake flours and breakfast foods.

Cane sugar.—The juice of the green stalks contains considerable amounts of cane sugar, and tropical varieties seem to be much sweeter than those grown in temperate regions. By removing the ear at the proper time, before the grains are fully grown, it is said that the stem may be made to store so much sugar as to rival sugar cane in sweetness. This sugar may be refined and crystallized, but cane, beets, and the sorghums offer competition sufficient to suppress the commercial development of this source, at least in the immediate future.

Fermented products.—Corn furnishes one of the cheapest and best materials for the production of fermented liquors. The juice of the stem has a limited use in this way, as have the green cobs left as a by-product of the canning industry; but the carbohydrates of the grain are of most importance.

The substance upon which the organisms of fermentation are allowed to act may be corn meal or some of the manufactured products of the grain, such as corn syrup, starch, or glucose; but a mash made from the sprouted grain is most commonly used. The distilled and purified product is grain alcohol, or some form of whiskey, depending upon the details of manipulation. The residue left after distillation is used for stock food.

By allowing fermentation to continue longer before distillation, the alcohol is changed into acetic acid. Much of the vinegar on the market is a derivative of this product, but commercial acetic acid is usually more profitably made in other ways.

Fuel.—Since much corn is grown in localities where wood and coal are scarce, it finds at times an important use as a fuel. The whole ears, the cobs, or the stalks may be used in this way. The cobs are especially good for kindling fires and for smoke fuel in the meat-packing industry. Attempts have been made to produce gas for fuel purposes by the destructive distillation of the stalks and cobs, and a good quality of gas results; but the process has never been worked out on a dependable commercial basis.

The use of the inedible parts of the plant for fuel is a commendable act of conservation; but this wasteful method of utilizing the energy stored in the grain must stand as a severe indictment against the transportation facilities and economic conditions of any country that permits it to occur while people in other parts of the world are dying of starvation.

The stem.—The dry stem contains material of nutritive value, but the low degree of digestibility and the complicated processes involved in preparation will long act as a limitation to its use as a food. Various parts of the stem are, however, adapted to other uses.

A compressed layer of the pith was formerly used as packing under the steel armor of battleships, its elasticity and absorptive power causing it to swell and fill holes made by solid shot. But the evolution of the methods of warfare has rendered this type of construction obsolete.

The pith is a source of almost pure cellulose. Its principal use is in the manufacture of nitrocellulose and its derivatives, and the product is said to be superior to that made from cotton. The vascular bundles and sclerenchyma make a good quality of paper, which, however, has not yet been able to compete with the products of the wood-pulp processes.

Cobs.—The ash of the cobs is rich in potash. The cobs of large-eared varieties are used for making pipe-bowls. All the woody parts of the plant, especially the cobs, are rich in pentosans, from which the pentose sugars and their derivatives are made. An infusion of the cobs is an excellent substitute for maple flavor.

Husks.—In earlier days, the husks were braided into mats and rugs, and when torn into fine shreds they formed a good substitute for straw for filling pillows and mattresses. The fiber of the husks may be spun and woven into a coarse cloth; it may also be used for making paper. In Mexico and parts of South America, the large, outer husks are used for inclosing *tamales* for cooking. The thin, inner husks are used in Latin America and other parts of the world for cigarette wrappers.

Medicinal value.—The only part of the maize plant definitely known to have a specific medicinal value is the silk of the immature ear. An infusion of this has been used beneficially for certain urinary disorders and venereal diseases, and, in a few instances, as a cardiac stimulant. The active principle is probably maizenic acid. Extracts or infusions of the leaves and husks are sometimes used in the home treatment of different ailments, but they are of doubtful value. Wet or dry poultices made from the meal or whole

grain are sometimes used, but their value lies in their great capacity for heat. Maize smut is sometimes used as a substitute for the ergot of rye.

Undeveloped possibilities.—The world has been slow to grasp the full potentialities of America's great gift to mankind. Its heavy yields, the ease with which it may be grown, and its adaptability to conditions soon gave maize a hearty welcome into every land in which it can be grown successfully; but it has been used principally to satisfy simple needs. Much of the total product has been fed to live stock without manufacture of any kind; and our recent attempts to minister to starving Europe have disclosed the fact that, in many countries, maize is considered unfit for human food.

The peculiarities of the endosperm preclude the possibility that maize may ever take the place of wheat as a source of flour for making white bread, for it is deficient in the gluten content necessary to give it the proper physical texture; but it can be made into wholesome, palatable foods of many kinds, and both theory and practice indicate that in balance of nutritive properties it is the equal of wheat. Now that the need for conservation is beginning to be felt, the lengthening list of its manufactured products is making for maize, in the economic life of the whole enlightened world, a place that no other plant can fill.

CHAPTER XXVI

MAIZE IN ABORIGINAL AMERICA[1]

Someone has attributed to the North American bison the decadence of that cultured race which has left in the mounds and other works of the Mississippi Valley the marks of a superior civilization. As the bison began to appear on the prairies in increasing numbers, the ease with which a living could be secured by following an instinctive bent lured the farmer and the artisan from their civilized pursuits and fixed habitations into the nomadic life of the hunter, which placed no premium on tendencies toward civilization.

In the desolate waste of the frozen north, on the other hand, or in the arid regions of the deserts, the actual demands of a meager existence sapped the energy and left little opportunity for anything but work.

Too much work is as demoralizing as too much play; but somewhere between these two extremes there was found in some parts of aboriginal America a condition in

[1] The material embodied in this chapter has been collected from many sources. In a few instances, original papers, or reprints of the older ones, have been consulted, but, inasmuch as none of the more important original sources, such as the works of Acosta, Sahagun, or De la Vega, have been available, dependence has been placed in résumés and extracts as given by historians of modern times. In connection with the discussion of some of the most striking topics, reference is made direct to the source of the information. No attempt has been made to deal in any critical way with mooted questions of history, archaeology, or ethnology, except in a few instances, where the historian's understanding of the botanical nature of the plant is clearly at fault and has led to misinterpretation.

which, although work was necessary for a comfortable living, yet intelligent action was rewarded with much leisure. This was the promise of agriculture, and the key to this industry was Indian corn. Only a few favored spots in all America supported races that approached a condition of civilization; and these were the localities where fixed habitations and relief from constant physical effort were made possible through the efficient cultivation of maize.

Maize areas.—By the close of the fifteenth century the cultivation of maize had become as widespread in both North and South America as conditions of soil and climate would permit. Its range extended from the Gulf of the St. Lawrence and the Dakotas far down into Chile and Argentina, but it was most successfully grown between the fortieth parallels (Fig. 8).

Peru and Mexico were the seats of the most advanced agriculture and general civilization reached anywhere in ancient America. Fixed habitations, well-built cities, and good government encouraged the tiller of the soil to conserve fertility and to improve his land from year to year. Agriculture was a highly respectable occupation, all grades of society taking part in it except the nobility and the military class in time of war. The women sometimes worked in the fields, but the heavy labor was mostly done by men.

In the moist, hot climate of the Amazon Valley, manioc largely took the place of maize as a staple food crop. But the highlands of eastern Brazil and the northern coast of South America supported a heterogeneous, nomadic population which depended upon maize for a part of its subsistence.

The maize area most influential in the colonization and development of America comprised all that section of the United States east of the arid plains region, and extended in some places as far as 50 miles into Canada. Hunting and agriculture were the dependable occupations. Maize was the chief staple food plant. The population lived for the most part in wigwams or other light huts of a temporary nature. The work of clearing the ground and cultivating the crops was left largely to the women. It was mostly a roving sort of life, and little progress was made in agriculture.

Here and there, however, strong tribes became well established, built good houses, and cultivated the same fields year after year. Early explorers tell of vast areas planted in maize and estimate in millions of bushels the amounts of grain stored in the largest villages. These communities were the centers around which a degree of civilization the equal of that of Mexico or Peru would doubtless have developed had the white man delayed his coming a few centuries longer.

Origin of maize culture.—Indian myths of the creation, the deluge, and the origin of civilization abound in tributes to the part played by maize, and this plant is the subject of every legend that attempts to explain the beginnings of agriculture.

The early Aztec felt himself the superman and boasted of his being a "corn-eater," while his barbarian neighbors, who took a precarious chance at a living by hunting, were mere "suckers of blood."[1]

One of the most elaborate myths found anywhere in the literature of the Indians comes from the Mayas of

[1] Bancroft (5), p. 344.

Yucatan. This recounts how certain gods, or godlike men, recently arrived in the land and much displeased with living conditions, planned to reclaim the natives from barbarism. After mature deliberation, four barbarian chiefs were sent to a distant land to get new ideas. They returned bringing with them the "ears of yellow maize and of white," which rounded out their scheme of existence and became their chief reliance for food.[1]

Another tradition of the Mayas makes corn the very breath of life that was breathed into man. Made of earth, he was without life; but, by means of maize, he was converted into flesh and blood.[2]

In an account of the Cañaris, two brothers escape the deluge by climbing a mountain in Ecuador. When the waters subside, they descend in search of food. Two parrots repeatedly visit the famishing men, giving them food and drink made of maize. One of the birds is captured, whereupon she miraculously changes into a beautiful woman. She gives the men the seed of maize and teaches them its culture and uses, and ultimately becomes the ancestress of the Cañari race.[3]

The Navajos say that they first knew of corn when a turkey hen came flying from the direction of the morning star and shook from her feathers an ear of blue corn.[4]

In a tradition of one tribe of the United States, the Great Spirit comes to earth in the form of a woman and falls asleep. On waking, she arises and walks through the land, while useful plants spring up around her. At the right and left grow pumpkins and beans, and from

[1] Bancroft (5), pp. 715–17.

[2] Payne (116), p. 357.

[3] *Ibid.*, pp. 361–62.

[4] Sturtevant (138).

her footprints comes maize. The spot where she slept gives rise to tobacco.

The fact that these traditions account for the introduction of maize in various miraculous ways and in different places has led some historians to believe that the plant had more than one place of origin; and the many varieties of the plant are cited in support of this theory. But, since we must reject so much of the mythical as to the manner of its origin, may we not reasonably question also the time, and to a less degree the place? A botanical study of the many varieties shows only superficial differences between them and points to a wild ancestor that was much like the modern plant.

It is probable that the podded character had been lost and the eight-rowed ear had made its appearance before the plant's usefulness and domesticability first appealed to the savage. The effect of cultivation has been chiefly to reduce the number, and increase the size, of the inflorescences, and to concentrate the fruit into one or a very few units.

Similarities in nomenclature and agricultural practice, together with what is known of the early migrations of Indian tribes, point unmistakably to Mexico or Central America as the locality in which the domestication of maize began. From here the plant made its way both northward and southward, passing on and on, from tribe to tribe, as its importance came to be appreciated. The number of stable varieties that were grown in 1492, the absence of any wild ancestral form, and the well-established customs and traditions surrounding the maize plant, point to a long period of domestication before the coming of the white man.

Evolution of maize culture.—Even when the barbarian had first come into contact with maize, and a dim realization of its value had awakened within him, anything like an efficient system of agriculture was still far in the distance; and the evolution of man's methods in dealing with the plant is scarcely less significant than its botanical evolution. Much aimless or superstitious experimental work must have been done, and many exasperating failures must have been experienced, before the working principles of the art were mastered; and in the traditions of the tribes we find more or less definite reference to these difficulties. No act of god or man in giving the seed of maize to a tribe was complete unless the gift was accompanied by directions as to its culture and uses; and, even then, successful manipulation required long experience.

A tradition of the Toltecs, who occupied Mexico long before the day of the Aztecs, will illustrate. Maize culture was at first very difficult, because of unfavorable weather. Famine and plundering raids by savage tribes destroyed a large part of the population, and agriculture was abandoned in a reversion to hunting. Long years after this, a chief planted a few grains of maize that he had saved, and the result was so encouraging that a new impetus was given to agriculture. Later, in the days of the first of the Montezumas, frosts caused the crops to fail for two successive years, and a drought in the third. Famine followed, and the discouraged farmers planted no maize the next year. But the season was favorable, and a bountiful crop grew spontaneously. This miracle revived an interest in agriculture; but failure had taught its lesson, and scientific methods of seed selection and

storage, planting, and cultivation began to be practiced. It was probably some such disaster as this that suggested the first system of irrigation.[1]

Among the shiftless, wandering tribes of both continents might be found every imaginable step in the evolution of agriculture, and many of these are suggested in the traditions of the more progressive tribes.

Man's first cornfield was a natural opening in the forest, or a spot where the trees had been accidentally killed by fire. The next step was to clear the ground roughly by girdling the trees and burning the underbrush. Ground cleared in this way produced from eighty to four hundred fold the first year; but the yield rapidly decreased in succeeding years until too low to be profitable, when the old tract was abandoned and a new one cleared. When this practice had exhausted all the land convenientaly located, and it became apparent that the friendship of some god had begun to wane, as evinced by the failing crops, the tribe moved on to a new locality. Civilization was impossible until the ability to select good soil and to retain its fertility made permanent settlements possible. In the areas of most intensive cultivation in later days, many kinds of fertilizers, such as manures, fish, ashes, or guano, were used very successfully.

It was a remarkable stroke of Providence, which, withholding from the native American any domesticable animal that could be used in tilling the soil, gave him in compensation the one important cereal adapted to cultivation by hand. With one or two exceptions of a crude nature, no sort of plow or harrow is known to have been used anywhere in ancient America.

[1] Payne (116), pp. 358–59.

The most primitive method of manipulation consisted of merely planting the corn in holes made with a sharp stick, and leaving it without further attention till harvest time. Gradually, the farmer learned the importance of killing weeds and loosening the soil and heaping it up around the plants for support.

The practice of planting corn in hills seems to have been universal, the number of plants in a hill often being as high as ten or twelve. The distance between the rows and between the hills in a row was dictated by moisture and fertility. To secure a good stand, the seeds were often germinated before planting, and care was usually taken to see that the seeds in a hill were spaced at some distance from one another. The compact hills seen in a modern cornfield, where the three or four stalks are often so close together that they are in actual contact with one another, was unknown to the Indian. He planted the corn in hills so that he could heap the soil around the plants in groups rather than singly, and he made the hill worth while by putting in it a large number of plants; but these were often so spaced that the plants covered an area a foot or more in diameter.

After the corn had reached the height of a few inches, beans were sometimes planted in the hills and allowed to twine around the corn plants as they grew. The cornfield was often made to support also an undergrowth of pumpkin vines.[1]

The simplest implements used in the cultivation of the crop were sharp sticks, shells, bones, or other objects

[1] An Indian story often told for the amusement of the children pictures the bean and the pumpkin as two suitors of the maize lady. The one, being favorably received, holds her in his embrace, while the rejected lover runs away over the ground.

FIG. 173.—A hill of corn. The growing of corn in hills has been practiced by the Indians for ages, and this ecological condition must be constantly kept in mind in theoretical considerations.

that could be used as they were found. Modifications of these implements to improve their efficiency led to the use of many ingenious devices. Sharpened sticks were hardened by being charred in the fire. Hoes of various types were made by fastening shells, bones, or pieces of wood or stone to handles, or by working a part of the trunk of a small tree into a flat blade, while a branch attached to it was made to serve as a handle. Spades were made in a similar way, one form consisting of a straight stick sharpened and charred at the lower end, and bearing the short stump of a branch as a place for the foot. In rare instances, the implements used in working the soil were made of copper or other metal.

Varieties of maize.—All the fundamental varieties of maize in existence today, as determined by the nature of the endosperm, seem to have been known to the various Indian tribes. The choice among available varieties of the one best suited to a particular set of conditions seems to have been made about as intelligently then as now. The Indian's taste for the gaudy kept in common use a wider range of colors than is known to the average American today. Sometimes the full array of white, reds, yellows, and purples were maintained in a single variety, and again pure strains were often propagated for generations, some of these, such as the "sacred corn" of the Navajos, showing striking color patterns.

Agricultural engineering.—Some of the most stupendous feats of engineering accomplished in prehistoric America, or anywhere in the ancient or medieval world, were connected with the growing of maize.

The simplest engineering projects were the "garden beds" of the Mississippi Valley.[1] In the tough sod of the prairies of southern Michigan and Wisconsin and northern Indiana are still to be seen ridges and mounds used for growing corn in ancient times. These beds consist of a series of parallel or regularly curved ridges, the construction of which must have called for a high degree of skill. They probably had their origin in the custom of planting the corn each spring in the ridge left by the cultivation of a row the previous year. The heaping up of the soil year after year finally built up a ridge that has endured in some places to the present. Sometimes the ridges were wide enough for but a single row, and again they were spaced at greater intervals and made wide enough for two or more rows.

Although the best-preserved examples of these structures are to be found about the western border of the Great Lakes, traces of similar works occur throughout the Mississippi Valley and the West Indies.

The construction of these beds was probably the work of that problematical race known as the Mound Builders rather than of the Indian of later days. Their vast extent—continuous areas of twenty to a hundred acres being known—indicates a stable government and a high degree of civilization. The dense population indicated by these and contemporary works of other kinds was doubtless supported largely by the cultivation of maize, inasmuch as many of the mounds that have been opened contain supplies of this grain and fragments of the plant.

[1] Critics disagree as to the significance of these works, some even doubting their connection with prehistoric agriculture. The résumé here given is based chiefly upon Schoolcraft (130), pp. 54–60.

The early culture of the Aztecs was developed on islands in the lakes of central Mexico, where the population has sought refuge from their enemies. As their island homes became crowded, rafts were built and covered with mud and tangled vegetation dipped up from the bottom of the lake. This mass was in time bound together with the roots of growing plants and became a floating garden. A tiny hut and a patch of corn made it complete, and the owner had a safe, portable farm that needed no fertilizers and no irrigation.

On the steep slopes of the Andes, the surface available for cultivation was often materially increased by terracing. Contour lines were marked with banks of earth or walls of stone, and soil was brought up from below to fill in the terraces. Irrigation was often employed to remove the one defect of this system of agriculture, and these terraces were said to have produced the heaviest yields of maize known anywhere in America.

In the desert valleys of Peru and Chile, the loose sand is often underlaid by a moist, fertile subsoil, which was sometimes made available by the removal of the sand. Some of the pits thus formed were as much as 20 feet deep and covered an acre or more. In these could be grown maize and other plants without irrigation.

But surpassing all other feats of engineering undertaken by the Indian, and making no mean showing beside similar works of the present day, were the gigantic irrigation projects of ancient Peru. The valleys and mountain sides of many parts of the Andes have only a scanty rainfall irregularly distributed; and, to secure a dependable supply of moisture for his cornfield, the Inca and his neighbors built aqueducts hundreds of

miles in length, bridging streams, and tunneling mountains, and doing the work so well that it stands in serviceable form in many places today. Irrigation was also extensively practiced in Mexico.

All these massive works of the past stand today as mute witness of the part that the maize plant played in the life of the native American. It was not only important enough to call forth this stupendous effort, but it also provided food in sufficient abundance to release enormous numbers of laborers for public works of this kind.

Harvesting and storage.—In most instances, the ears of corn were left on the stalk in the field until dry. Since the ears of many varieties stood erect at maturity, it was the custom in some places, as soon as the corn was mature, to break the stalks over just below the ears so that the latter would hang downward and be sheltered by the husks while drying.

The ripe ears were sometimes spread out on platforms to become thoroughly dry. At other times, the ears were broken off and the husks pulled back and braided together, and long chains of the ears thus united were hung over poles to dry. The grain was sometimes shelled before storage, but was often stored in the ear.

A favorite storage place among all tribes was in pits in the ground. In Eastern North America, these were lined with bark, leaves, or dried grass. In Mexico and Peru, the grain was often stored in these pits in vessels of pottery. In many places, there was used a type of crib made of poles. Each family had one or more pits or cribs containing enough grain for its own use, and there were often great stores reserved for the common use of the whole community in cases of emergency.

Uses.—The Indian's simple requirements discovered only the most obvious and most fundamental uses of the maize plant. The part most used was, of course, the mature fruit, but other parts had a recognized value.

In preparing the dry grain for use, the first step was to remove the tough, leathery hull of each grain. Sometimes the dry grain was crushed in a stone or wooden mortar and the hulls sifted out. In some places, it was customary to boil the grain and remove the pericarps one at a time by hand. This method was especially applicable to the large grains of the varieties grown about Cuzco, Peru. But the most popular method was to boil the corn in water to which ashes or lime had been added. This method, which loosens and partly dissolves the hulls without impairing the food value of the grain, is still extensively used by civilized man in making lye hominy.

The hulled grain was either boiled and eaten as hominy, crushed and made into porridge, or made the basis of a bread or similar food. Typical of the last were the *tortillas* of the Mexican Indians, a kind of bread known under various names to all maize-growing tribes. The boiled corn was crushed and made into a thin batter, which was baked in thin cakes on a flat rock or in an earthen pan. These cakes were the staple food made from corn. *Tamales* were pies made of various kinds of meat wrapped in masses of dough, the whole being inclosed in a corn husk or banana leaf and baked or boiled.

Pop corn was known in many localities, and parched corn was widely known and used in many ways. The latter, when ground, was often used on long journeys

where the maximum of food was to be carried in a small packet.

Though the Indian was fully aware of the substantial way in which maize supplied some of his fundamental needs, yet his keenest sense of pleasure came from the drinks that it afforded. These he had in almost endless variety. One god is said to have given the Mexicans nine excellent recipes at one visitation. Some of the drinks were nothing more than thin gruels flavored with salt, pepper, cacao, or herbs, or sweetened with honey or with the juice of green cornstalks. Others were fermented. No method of distillation seems to have been known, and the alcoholic content of these drinks must have been low; but a few were so strong that their use was forbidden, except on very special occasions. The most popular of the fermented drinks was *chicha*, which was widely known in many forms. It was prepared in a variety of ways, the dry, parched, or sprouted grain being ground or masticated and then mixed with water and allowed to ferment.

A long-continued, exclusive diet of maize always leads to digestive disorders, and the Indian found that the objectionable feature was removed by mixing with the food some substance affording a chemical or mechanical irritant to act as a stimulant. This is said to have been the cause of the popularity of the chili pepper in Mexico. Powdered limestone, clay, or saltpeter was used for the same purpose; and, in some parts of South America, ants were mixed with the food, their chitinous shells and the formic acid of their bodies doubtless having the desired effect.[1]

[1] Payne (116), pp. 406–7.

The New World afforded no greater delicacy than the green ear of corn, the "roasting ear" of modern times. In season this was a favorite food everywhere. It was eaten raw, boiled, or roasted; and the Indian was the inventor of the mixture of green corn and beans known as "succotash." The juice of the stem, especially in subtropical climates, was often extracted and boiled down to a syrup, or fermented and used as a drink.

In Mexico and some other parts of America, corn was regularly depended upon for a part of the food supply of the flocks of domesticated ducks, geese, and turkeys; but, with the exception of the llama and its relatives in South America, there was no domesticated animal for which the fodder of the plant might furnish food. The stalks, leaves, and husks were usually wasted except for the limited use that was made of them for mats, beds, thatching, or fuel. The silks of the plant and the ashes of the cobs were supposed to have medicinal values.

Maize and religion.—The Indian's religion was closely linked with his daily life. His gods were personifications of the natural forces that he saw at work about him, and at whose mercy he felt himself to be. A pious attitude, therefore, was good policy, for it was likely to win for him the good will of the powers that shaped his environment.

Since maize was one of his greatest blessings, it must itself be the work of a deity, but many other deities were necessarily connected with its existence. Consequently, parts of the maize plant, and symbolical idols designed after parts of it, played important parts in the numerous ceremonies connected with the manipulation of the crop.

In most localities, the maize spirit was a woman, the *maize-mother*. She received much attention in religious ceremonies, and many offerings were placed on her altar. But her power as a deity was thought to be limited; she was dependent upon both the sun-god and the rain-god for the success of her work. The only idol of the ancient Mexicans that survived the foolish fanaticism of the early missionaries in that country is a basalt image of this goddess.[1]

The charms that were practiced and the rites that were performed to protect the crop are exemplified in "The Song of Hiawatha." Inaccuracies in the historical account upon which Longfellow based this poem are responsible for certain errors of detail, but the spirit of the Indian's respect for the plant is faithfully shown.

Three incidents in the life of the corn plant were celebrated with especially elaborate ceremonies in different parts of America. These were the germination of the seeds, the formation of the ear, and the harvest. The first two of these, coming at critical times in the activity of the plant, took the nature of propitiatory offerings. The last was more on the order of a thanksgiving.

In Peru, the time between planting and the appearance of the plants above ground was a time of fasting for all classes. Boiled maize and herbs were the only foods allowed, and strict limitations were placed upon the drinking of fermented liquors. The same ceremony took on a more elaborate form in Mexico. Offerings of corn and small animals were made to the maize-goddess and her associates, especially the rain-goddess, whose

[1] Payne (116), p. 469.

help seems to have been much needed. Houses were elaborately decorated, and sham battles were staged in the temple of the goddess of harvests.

The Mexican rites of "the long-haired mother" came at the time of the formation of the ear on the corn plant and lasted eight days. It took the form of a dance beginning at the end of each day. The principal part of the ceremony was a dance performed by the women, who shook and tossed their hair in imitation of the silks of corn. A prominent figure among the dancers was a slave girl dressed and painted in imitation of the corn plant. It is doubtful if she was allowed to know the conclusion of the ceremony, for she was intended as a sacrifice to the maize-mother, and the success of the whole procedure depended upon the vigor with which she danced and the pleasure that she derived from the occasion. On the last night, the dance lasted till daybreak, when the chiefs and warriors appeared on the scene, and all danced the death dance. Then, in a solemn procession, they all moved to the teocalli and killed the victim, offering her heart to the maize-mother. Until this rite had been concluded, "no one might eat of the principal luxury of the New World, the sweet, green ear of maize; for the corn in that case would have failed to ripen."[1]

The harvest celebration is illustrated by a custom of the Zapotecs of Mexico. At harvest time, the whole population went in ceremonial procession to the maize fields, where the finest ear was selected. This was taken to the temple, and, after a sacrifice to the harvest-god, it was carefully wrapped and kept till planting time.

[1] Payne (116), pp. 464–69.

Then another procession was formed, and the ear was taken back to the field and buried in a specially prepared pit, while sacrifices were being offered. Immediately after this, planting began. As harvest time approached again, the priests went once more to the field and dug up the buried ear and distributed the grains among the people as talismans. This idea in keeping the best ear buried in the field was to exert a good influence upon the growing crop.

In the sacred architecture and art of the Indians, maize had a deserving place of prominence, being both artistic and worthy of veneration. The best examples of this use of the plant were found in the temple at Cuzco, the most magnificent in Peru.[1] This temple was elaborately decorated in gold, silver, and precious stones. On the floor of the great salon were twelve immense silver vases filled with corn. The old Spanish account says that these were as high as a good lance and so large that two men with outstreched arms could hardly reach around them. In the gardens around the temple only gold and silver implements were used in tilling the corn. Inside the temple was a garden filled with life-size maize plants made of gold and silver.

The myths and legends of this primitive people centered around the corn plant might be multiplied almost without limit, as might also the accounts of the religious rites and works of art and architecture inspired by the plant, for every tribe had its own characteristic traditions, works, and practices. But a more detailed account soon involves repetition, and the Indian instead of corn is likely to become the chief center of interest.

[1] Prescott (120), pp. 101–2.

After all, the theme involved throughout is a simple one, being the reaction of a simple intellect toward a fundamental factor of its environment.

America's gift to mankind.—The years have rolled away since first the white man reached this shore of the Atlantic, and the Indian race as a race will soon be no more. Did Europe interrupt in America a budding drama, or had the climax been reached and passed? As a consequence of the part that we have played, we like to believe it was the latter; and the limitations of the red race and their environment strengthen our belief. But now, that he is passing from the scene, what has been the Indian's contribution to civilization? To the Latin he gave some gold and silver; to the Anglo-Saxon, food and shelter until his colony was firmly rooted; and he enriched the languages of Europe with a few new terms, and her literature with a few new elements of imagery; but his great and enduring gift to the whole world was maize. This plant he took from vegetable barbarism and made of it the aristocrat of the cereals; and today it feeds a large proportion of the world's population, and is the basis of the life and prosperity of the great nations of America as truly as it ever was in the brightest days of Aztec or of Inca.

CHAPTER XXVII

MAIZE IN AMERICAN LIFE

The spirit of a nation, as expressed in its manners, customs, arts, and literature, necessarily bears a strong imprint of the leading ways that its citizens have of turning natural resources into the necessities and luxuries of daily life. As a factor in the economic life of the greatest of the nations that have grown up in the homeland of maize, this plant and the industries that are based upon it are of supreme importance. It is but a fulfilment of our expectations, then, to find on analysis of our modern national life that the maize plant is inseparably interwoven into the spirit of America.

Three hundred years ago, on the inhospitable shores of New England, it began its career of Americanization. Winter was coming on, and the Mayflower's supplies were low; the great venture promised to end in dismal failure. But the discovery of an abandoned store of Indian corn saved the colony from extinction; and the following season the colonist was able to produce a harvest of maize so bountiful that it insured the success of his project. We shall never know how prominently the name of maize figured in the Pilgrim's prayers on the occasion of that first Thanksgiving.

As an agricultural achievement, the success of the Plymouth colony this first year is unparalleled in history. In a new country, where the soil was mediocre and the climate strange, the Puritan planted a crop whose ways he little knew, and, with only a savage for his

teacher, he learned his lesson in agriculture and put it into practice so effectively that his results eclipsed the best that he had ever been able to do in England. As news of successes like this made its way back to Europe, there began to appear before the eyes of the oppressed a vision of America as the land of opportunity.

On down through the years of colonial life, and through the period of expansion and development of the young republic, maize has continued to be the key to opportunity. It grew luxuriantly with little preparation of the soil and little cultivation; its growing season was marked by no extremely rigorous climatic conditions; and it had few enemies that could not successfully be avoided. It was an ideal crop for the conditions, promising almost certain results to the man who could not afford to take a chance.

The grower of maize is today in a position to enjoy a large degree of economic independence. The product of his labor can be turned into meat, bread, poultry, or dairy products without leaving the farm and with the minimum of dependence upon other industries. The many uses to which corn and its farm products can be put, and the consequent independence that may be exercised in disposing of the crop, greatly increase the difficulty of the speculator who attempts to manipulate prices, and insures a relatively advantageous market condition.

Mention of the Corn Belt suggests large, prosperous, well-stocked farms, substantial buildings, good roads, good schools, churches, colleges, and universities, and clean, orderly towns and cities as commercial centers. It is a land of prosperity, intelligence, and contentment.

Many of these blessings may be attributed to the innate temper of the pioneers in this region, but to the peculiar requirements and advantages of the corn industry must go much credit for the qualities that make the Middle West the embodiment of the best that there is in the ideal Americanism.

Certain steps in the manipulation of the crop have contributed to the long list of social occasions that have had so much to do with the shaping of American ideals. In earlier days the logrollings and quilting bees were varied in season with an occasional husking bee. Some corn was usually husked on these occasions, but this was not necessarily all the good that came out of the event. It afforded one of the few opportunities in those days for social intercourse and fostered the formulation and development of fundamental political and economic policies. Many a colonial romance, too, had its beginning in the finding of a red ear of corn by some novice too timid to make a start unaided.[1]

The maize plant has thus far inspired few works of art, literature, or architecture, but these fields offer promising possibilities. These are the products of the maturity of a nation, and America is still in the period of growth and development. The beauties of her resources will make their best appeal felt only after the climax of economic development has been passed. The

[1] In the early New England husking bees it was the privilege of the youth who found a red ear of corn to kiss any girl that he might choose from those present; and, if we are to believe the stories of the time, it was no uncommon thing for a red ear once found to be hidden in the pile of unhusked ears and repeatedly rediscovered and used. Imagination can picture the opportunity lost through a lack of understanding in those days of the manner of inheritance of the red pericarp.

utilitarian bent is conducive to the exercise of a single-track mind, which is often intolerant of a search for beauty or truth in a place where usefulness is usually sought.

Maize has ornamental properties that will in time give it a place in decorative work. It has already been utilized in the commercial world in this way, having been worked into some attractive advertising designs. In fairs and expositions, also, the ears and grains have been effectively used in symbolical decoration.

The most magnificent examples of the latter ever attempted were the corn palaces constructed in Iowa during the closing years of the past century. The idea of these works originated in Sioux City, and those built there in successive years from 1887 until 1895, or later, attracted wide attention and were copied in many other cities, but only in miniature (see Fig. 174).

A large building, 100 to 250 feet square, with elaborate gables, domes, towers, and pinnacles, some of the latter more than 150 feet tall, was constructed of wood and then completely covered with ears, stalks, husks, and grains of corn, and with parts of other agricultural plants, arranged in attractive designs. In some instances, elaborate designs representing farm scenes, nursery tales, and landscapes were worked out in grains of different colors.[1]

Such works as these silently testify to the place that the plant holds in the life of the people in the heart of the corn country; but they still bear the stamp of commercialism, and fade into insignificance as works of art when compared with the symbolical ornamentation

[1] Plumb (118), pp. 230–32.

of the ancient Inca Temple of the Sun.[1] The inspiration of a modern work of art that will be an appreciation of maize for its aesthetic value alone belongs to the days that are yet to come. The poet and the essayist have made more extended use of the material offered them,

FIG. 174.—A corn palace built at Sioux City in 1889 (after Plumb, by permission of the *Breeders' Gazette*).

and the literature of the world is richer by many a gem whose theme is the sentimental appeal of maize. Both the lore of the Indian and the beauty and fragrance of the prairie cornfield of today have done their part in the way of inspiration.

In the well-known "Song of Hiawatha," Longfellow has immortalized many sketches of the life of the North

[1] See p. 215; also Prescott (120), pp. 101–2.

American Indian. Among these is an account of the manipulation of the maize crop by Hiawatha, the mythical hero of the tribes of the Eastern United States. Here unfolds a vivid picture of the preparation of the soil, the planting and tillage of the crop, and the festivities of the harvest, and, accompanying all these activities, the rites and ceremonies designed to charm away the enemies of the plant.

Bayard Taylor's "Mondamin" pictures the coming of the maize deity, Mondamin, to the Ojibways of the Great Lakes region.[1] Osséo, an Indian Prince, while undergoing a religious fast, is visited by Mondamin in the guise of a youth dressed in brilliant green and adorned with waving plumes. On six successive days the two test their strength in a friendly wrestling bout, and, before the seventh test, the god foretells his own defeat and directs Osséo to bury him in the earth when he has been vanquished. The prince follows the instructions and is rewarded in due time with the first corn plant the tribe has ever seen. To the Indian each new season's wrestle with the difficulties of producing a crop was a pageant representation of this mythical struggle; and the poet, carrying the figure down to the present, sees Mondamin still in our cornfields. And, although many times dead and buried in the ground,

> Mondamin remained, and still remains;
> His children cover all the boundless land,
> And the warm sun and frequent mellow rains
> Shape the tall stalks and make the leaves expand.
> A mighty army he has grown: he drills
> Their green battalions on the summer hills.

[1] Longfellow also gives a version of this myth with Hiawatha as the human hero of the contest with Mondamin.

And when the silky hair hangs crisp and dead,
Then leave their rustling ranks the tasseled peers,
In broad encampment pitch their tents instead
And garner up the bright autumnal ears;
The annual storehouse of a nation's need,
From whose abundance all the world may feed.

The "Corn Song," of Godfrey Marks, has been set to music and holds a merited place in the public-school music of many sections of the Middle West.

Whittier, whose word pictures of early New England country life will live forever, puts into verse now and then the sentiment of the husking bee or scenes in the home or camp, where the pioneer partakes of his simple fare, largely the product of the maize plant. "The Huskers" closes with that well-known lyric, "The Corn Song."

Edward Everett selected a fitting subject for his eloquence when he said:

Drop a grain of our gold, of our blessed gold, into the ground, and lo! a mystery; it softens, it swells, it shoots upward; it is a living thing; it arrays itself more glorious than Solomon in its broad, fluttering, leafy robes. . . . . It spins its verdant skeins of vegetable floss, displays its dancing tassels; and at last ripens into two or three magnificent batons, each of which is studded with hundreds of grains of gold, every one possessing the same wonderful properties as the parent grain, every one instinct with the same marvellous reproductive powers.

To-day a senseless plant, to-morrow it is human bone and muscle, vein and artery, sinew and nerve, beating pulse, heaving lungs, toiling brain. Heaped in your granaries this week, the next it will strike in the stalwart arm, and glow in the blushing cheek, and flash in the beaming eye; till we learn at last to realize that the slender stalk that we have seen shaken by the summer breeze, bending in the cornfield under the yellow burden of harvest,

is indeed the "staff of life," which since our nation's earliest history has supported the toiling and struggling masses on the pilgrimage of existence.[1]

Out of the enthusiastic interest in the adoption of a national flower on the occasion of the four hundredth anniversary of the discovery of America, there came a number of tributes to the maize plant.[2] These should arouse in every American a little deeper feeling than for mere physical hunger satisfied.

A poem of this period, doubtless the most fitting appreciation that we have of this plant most eminently qualified to become the nation's emblem, is a fitting conclusion.

Blazon Columbia's emblem,
The bounteous golden corn!
Eons ago of the great sun's glow
And the joy of the earth 'twas born.
From Superior's shore to Chile,
From the ocean of dawn to the west,
With its banner of green and silken sheen
It sprang at the sun's behest;
And by dew and shower from its natal hour
With honey and wine 'twas fed
Till the gods were fain to show with men
The perfect feast outspread;
For the harvest boon to the land they loved
Was the corn so rich and fair.
Nor star nor breeze o'er the farthest seas
Could find its like elsewhere.

[1] In response to a toast at a dinner of the United States Agricultural Society, 1855.

[2] See the symposium on maize as the national flower in *The Arena*, VIII (1893), 92–114.

In their holiest temples the Incas
Offered the heaven sent maize,
Grains wrought of gold in a silver fold
For the sun's enraptured gaze,
And its harvest came to the wandering tribes
As the god's own gift and seal;
And Montezuma's festal bread
Was made of its sacred meal.
Narrow their cherished fields, but ours
Are broad as the Continent's breast,
And lavish as leaves the rustling sheaves
Bring plenty and joy and rest;
For they strew the plains and crowd the wains
When the reapers meet at morn,
Till the blithe cheers ring and west winds sing
A song for the garnered corn.

The rose may bloom for England,
The lily for France unfold,
Ireland may honor the shamrock
And Scotland her thistle bold;
But the shield of the Great Republic,
The glory of the west,
Shall bear a stalk of the tasseled corn,
Of all her wealth the best.
The arbutus and the golden rod
The heart of the north may cheer,
And the mountain laurel for Maryland
Its royal clusters rear,
And jasmine and magnolia
The crest of the south adorn;
But the wide Republic's emblem
Is the bounteous golden corn.[1]

[1] "Columbia's Emblem," by Edna Dean Proctor.

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